CRANFIELD UNIVERSITY

G. J. DAVIES, B.Sc. (Hons), M.Res., M.Sc.

TOWARDS AN AGENT-BASED MODEL FOR RISK-BASED REGULATION

SCHOOL OF APPLIED SCIENCES

PhD THESIS
Academic year: 2009/2010

Supervisor: Prof. Simon. J. T. Pollard
Co-Supervisor Dr. Sophie Rocks
September 2010

This page is intentionally blank

CRANFIELD UNIVERSITY

SCHOOL OF APPLIED SCIENCES

PhD THESIS

Academic Year 2009/2010

G. J. Davies, B.Sc. (Hons), M.Res., M.Sc.

TOWARDS AN AGENT-BASED MODEL FOR RISK-BASED REGULATION

Supervisor: Prof. Simon. J. T. Pollard

Co-Supervisor Dr. Sophie Rocks

September 2010

This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

This page is intentionally blank

ABSTRACT

Risk-based regulation has grown rapidly as a component of Government decision making, and as such, the need for an established evidence-based framework for decisions about risk has become the new mantra. However, the process of brokering scientific evidence is poorly understood and there is a need to improve the transparency of this brokering process and decisions made. This thesis attempts to achieve this by using agent-based simulation to model the influence that power structures and participating personalities has on the brokering of evidence and thereby the confidence-building exercise that characterises risk-based regulation.

As a prerequisite to the adoption of agent-based techniques for simulating decisions under uncertainty, this thesis provides a critical review of the influence power structure and personality have on the brokering of scientific evidence that informs risk decisions. Three case studies, each representing a different perspective on risk-based regulation are presented: nuclear waste disposal, the disposal of avian-influenza infected animal carcases and the reduction of dietary salt intake. Semi-structured interviews were conducted with an expert from each case study, and the logical sequence in which decisions were made was mapped out and used to inform the development of an agent-based simulation model.

The developed agent-based model was designed to capture the character of the brokering process by transparently setting out how evidence is transmitted from the provider of evidence to the final decision maker. It comprises of two agents, a recipient and provider of evidence, and draws upon a historic knowledge base to permit the user to vary components of the interacting agents and of the decision-making procedure, demonstrating the influence that power structure and personality has on agent receptivity and the confidence attached to a number of different lines of evidence. This is a novel step forward because it goes beyond the scope of current risk management frameworks, for example, permitting the user to explore the influence that participants have in weighing and strengthening different lines of evidence and the impact this has on the final decision outcome.

Keywords: Agent-based simulation; power; personality; weight of evidence; risk regulation; policy development

This page is intentionally blank

ACKNOWLEDGEMENTS

I would like to thank the Engineering and Physical Sciences Research Council (EPSRC) for funding this research. I would also like to thank Professor Simon Pollard, my principal supervisor, for being a true mentor; providing support where it was needed and sufficient pressure to ensure I got through this process. Also, my appreciation to my co-supervisor, Dr Sophie Rocks, for the great support and assistance. I would also like to thank Professor Graham Kendall, Dr Emma Soane and Dr Michael Li for their supervision and intellectual input during this period.

Access to experts made this research possible. I cannot name them personally for reasons of confidentiality, but I would like to extend my gratitude to each of them for giving up their time to take part in this research.

I would also like to thank my family for all their love and support. I would particularly like to thank Roberta, my beautiful gorgeous wife, for the many discussions, countless cups of coffee and midnight snacks that she made me during the many sleepless nights throughout this PhD. Also my sincere thanks goes to my pastor, Rev Biyi Ajala, for his prayers and support, my very good friends Ade, Dan, Allison and other members of HFWM and my parents (David and Elizabeth) for all their love, prayers and support.

Most of all, I would like to thank God for bringing me this far. You taught me to be like the ants and become self-motivated (Proverbs 6:6-8). You never gave up on me, even when I had lost all hope that I would get this far!

This page is intentionally blank

LIST OF PUBLICATIONS AND DISSEMINATION

G. J. Davies; G. Kendall; E. Soane; J. Li; F. Charnley; S. J. T. Pollard (2010) Regulators as 'agents': power and personality in risk regulation and a role for agent-based simulation. Journal of Risk Research,

Li, J., Kendall, G., Pollard, S., Soane, E., Davies, G. and Bai, R. (2010) A decision support approach for group decision making under risk and uncertainty. *Proc. International Conference on Logistics Systems and Intelligent Management (ICLSIM 2010),* Harbin, China, IEEE, ISBN: 978-1-4244-7331-1, pp. 1856-60.

Li, J. Pollard, S. Kendall, G. Soane, E. **Davies, G.J.** (2009) Optimising risk reduction: an expected utility approach for marginal risk reduction during regulatory decision making. Reliability Engineering & System Safety.

G.J. Davies, G. Kendall, E. Soane, J. Li and S.J.T. Pollard (2009) "An Investigation into regulatory decision making – the influence of personality and power" Paper and presentation, Annual SRA-E Meeting, Karlstad (platform for presentation)

G.J. Davies, and S.J.T. Pollard (2009) "Environmental Regulation in practice" MSc Lecture, Cranfield University.

G.J. Davies, G. Kendall, E. Soane, J. Li and S.J.T. Pollard (2009) "An investigation into regulatory decision making: using agent-based simulation" EPSRC Uncertainty Network Meeting, London

Pollard, S.J.T. **Davies, G.J.** Coley, F. Lemon, M (2008) "Better environmental decision making – recent progress and future trends". The Science of the Total Environment. 400 (1-3):20-31.

G.J. Davies, G. Kendall, E. Soane, J. Li and S.J.T. Pollard (2008) “An investigation into regulatory decision making: using automated decision makers” United Kingdom Climate Impact Programme (UKCIP), London (poster presentation).

This page is intentionally blank

TABLE OF CONTENTS

ABSTRACT ..... **I**

ACKNOWLEDGEMENTS ..... **III**

LIST OF PUBLICATIONS AND DISSEMINATION ..... **V**

LIST OF FIGURES ..... **XIII**

LIST OF TABLES ..... **XX**

LIST OF ABBREVIATIONS ..... **XXII**

CHAPTER 1 INTRODUCTION **1**

1.1 CHAPTER STRUCTURE 1

1.2 BACKGROUND TO THE RESEARCH 1

CHAPTER 2 RESEARCH AIM AND OBJECTIVES **7**

2.1 CHAPTER STRUCTURE 7

2.1.1 Research aim *7*

2.1.2 Research Objectives *7*

2.2 THESIS STRUCTURE 8

2.3 RESEARCH DELIVERABLES 10

CHAPTER 3 LITERATURE REVIEW **12**

3.1 CHAPTER STRUCTURE 12

3.2 OBJECTIVE AND METHODS USED FOR CONDUCTING THE LITERATURE REVIEW 13

3.3 THE DISPARITY AND COMPLEXITY OF RISK-BASED REGULATION 14

3.4 THE BROKERING OF SCIENTIFIC EVIDENCE IN RISK-BASED REGULATION 21

3.5 POWER & PERSONALITY 28

3.5.1 Influence of power *28*

3.5.2 Influence of Personality *33*

3.6 AGENT-BASED MODELLING AND SIMULATION 39

3.7 AGENT-BASED MODEL FOR SIMULATING THE BROKERING OF EVIDENCE IN RISK-BASED REGULATION 45
3.8 CHAPTER SUMMARY AND CONCLUSIONS 56
CHAPTER 4 RESEARCH METHODOLOGY 61
4.1 CHAPTER STRUCTURE 61
4.2 DESCRIPTION OF OPTIONS FOR METHODOLOGICAL CHOICE 61
4.3 PHASE 1 70
4.3.1 In-depth unstructure interviews to explore the dynamics of the brokering of evidence in risk-based regulation 70
4.3.2 Selection of three real-world case studies characterising the breadth of conditions under which scientific evidence is brokered in risk-based regulation 72
4.4 PHASE 2 77
4.4.1 In-depth semi-structured interviews to describe the dynamics brokering of evidence in the three selected case studies 77
4.4.2 Development of a research framework capable of capturing the logic of the brokering of evidence in risk-based regulation 81
4.5 PHASE 3 83
4.5.1 Simulating the effect power structure and personality have on the brokering of evidence in risk-based regulation 88
4.6 CHAPTER SUMMARY AND CONCLUSIONS 90
CHAPTER 5 EXPLORATORY STAGE 92
5.1. CHAPTER STRUCTURE 92
5.2. IN-DEPTH UNSTRUCTURED INTERVIEWS CARRIED OUT TO EXPLORE THE DYNAMICS OF THE BROKERING OF EVIDENCE IN RISK-BASED REGULATION 92
5.3. SELECTION OF THREE REAL-WORLD CASE STUDIES THAT CHARACTERISE RISK-BASED REGULATION 102
CHAPTER 6 DESCRIPTIVE STAGE 115

6.1. CHAPTER STRUCTURE 115
6.2. IN-DEPTH SEMI-STRUCTURED INTERVIEWS 115
6.3. DEVELOPMENT OF THE RESEARCH FRAMEWORK 130
6.4. CHAPTER SUMMARY AND CONCLUSIONS 142

CHAPTER 7 MODEL DEVELOPMENT 145

7.1. CHAPTER STRUCTURE 145
7.2. PRESENTATION OF THE DETERMINISTIC MODEL 149
7.3. PRESENTATION OF THE DYNAMIC MODEL OF RECIPIENT'S RECEPTIVITY 160
7.4. PRESENTATION OF THE DYNAMIC MODEL OF CONFIDENCE BUILDING 174
7.5. CHAPTER SUMMARY AND CONCLUSIONS 180

CHAPTER 8 PROOF OF CONCEPT 186

8.1. PROOF OF CONCEPT STUDY 186
8.2. CHAPTER SUMMARY AND CONCLUSIONS 196

CHAPTER 9 DISCUSSION 198

9.1 INTRODUCTION 198
9.2 THE APPROACH 199
9.3 RESULTS FROM THIS STUDY 204
9.4 GENERAL APPLICATIONS 208
9.5 FURTHER DEVELOPMENT OF THE TWO-AGENT MODEL 210

CHAPTER 10 CONCLUSIONS AND FUTURE WORK 213

REFERENCES 217

APPENDIX A: EXPLORATORY INTERVIEW TRANSCRIPT 246

APPENDIX B: SEMI-STRUCTURED INTERVIEW SCHEDULE ERROR! BOOKMARK NOT DEFINED.ERROR! BOOKMARK NOT DEFINED.

APPENDIX C: PARTICIPANTS BY SECTOR ERROR! BOOKMARK NOT DEFINED.ERROR! BOOKMARK NOT DEFINED.

APPENDIX D: SEMI-STRUCTURED INTERVIEW TRANSCRIPT CASE STUDY 2..... ERROR! BOOKMARK NOT DEFINED.ERROR! BOOKMARK NOT DEFINED.

APPENDIX E: SEMI-STRUCTURED INTERVIEW TRANSCRIPT CASE STUDY 3..... ERROR! BOOKMARK NOT DEFINED.ERROR! BOOKMARK NOT DEFINED.

APPENDIX F: SOURCE CODE OF THE MODELERROR! BOOKMARK NOT DEFINED.ERROR! BOOKMARK NOT DEFINED.

APPENDIX G: PUBLISHED WORKERROR! BOOKMARK NOT DEFINED.ERROR! BOOKMARK NOT DEFINED.

This page is intentionally blank

LIST OF FIGURES

Figure 1: Simplified illustration how power and responsibility are delegated from central Government to its departments and agencies, (a) and information (robust evidence) is filtered back up to inform further policy development (b)..... 3

Figure 2: Risk management framework (After DETR et al., 2000)..... 19

Figure 3: Personal and organizational features that influence risk-based decisions (After Johnson, 1992; Content, 2005)..... 20

Figure 4: An example structure of the institutional sub-components involved in the decision on reviewing post-closure safety cases. Individual boxes are often populated by an array of domain experts. In this case, representatives of the regulator's policy function make recommendations to the Government Department and ultimately the Secretary of State regarding the re-authorisation of a facility (adapted from Yearsley et al., 2001)..... 23

Figure 5: A conceptual simplification of the brokering of evidence and knowledge..... 24

Figure 6: The receiving, processing and passing-on of evidence and knowledge. 26

Figure 7: French and Raven's (1959) five forms of power related to the brokering of evidence and knowledge in risk-based regulation..... 29

Figure 8: Matrix used to assess the identified case studies. 74

Figure 9: Illustrating the process used to carry out a review of the different regulatory frameworks published by Government departments and agencies in the UK..... 75

Figure 10: Model of a process for acquiring and securing scientific data (Adapted from OXERA (2000)..... 76

Figure 11: Interview Schedule, where the change in the horizontal distance between the directional arrows illustrates how the focus of decisions moved from the general, to the specific and back again. 79

Figure 12: General processes by which the author investigated the brokering of evidence in risk-based regulation. Representing how formal roles () set out in Government guidance and the directional flow of information () were coded within Microsoft Excel to create a two-agent simulation model. 86

Figure 13: Methodology used to triangulate insights. Where, each angle of the large triangle represents one case study and each angle of the smaller triangles represents how insights regarding the brokering of evidence were gathered. 90

Figure 14: Connected account of how respondents were identified, interviews were recorded and how transcripts were processed and analysed..... 94

Figure 15: Items categorised under the three main themes of the brokering process in risk-based regulation; the receiving stage, the processing stage and the passing-on stage. 95

Figure 16: Connected account of how three case studies representing the breadth of risk-based regulation were selected. 103

Figure 17: illustrates how the three selected case studies (dietary salt intake, disposal of avian influenza animal carcasses, and nuclear waste disposal) range in the extent to which they are characterised by relative levels of public dread, scientific uncertainty, accountability and inflexibility of the regulatory frameworks from which decisions are made. 104

Figure 18: Decision making process related to the Food Standards Agency's development of the 6 gram per day salt intake guideline. 109

Figure 19: Decision making process related to the Department of Environment and Rural Affairs coordinated effort for the disposal of avian influenza infected animal carcasses. 110

Figure 20: Decision making process related to the Environment Agency's assessment of a post-closure safety assessment. 111

Figure 21: Connected account of the process followed to develop a semi-structured interview schedule, record, transcribe and abstract heuristic codes representing the process evidence in brokered in each case study. 116

Figure 22: Different stages of the brokering process characterising the dietary salt intake case study 123

Figure 23: Different stages of the Environment Agency's regulatory decision whether to continue Driggs license to dispose of nuclear waste. 124

Figure 24: Different stages of the EA regulatory decision whether to continue Driggs license to dispose of nuclear waste. 125

Figure 25: TESLA™'s use of evidence support logic (ESL) to represent how a number of lines of evidence (LOE) inform a group risk-based decision (http://www.quintessa-online.com/TESLA™/). 131

Figure 26: Maths behind evidence support logic (Li, Unpublished) 132

Figure 27: Logic supporting the influence power structure and personality has on the brokering process (the receiving, processing and passing-on of scientific evidence and knowledge. 136

Figure 28: The logic set out to calculate recipient receptivity. 137

Figure 29: Logic behind incorporating power structure and personality influences within the research framework. 138

Figure 30: illustrating the logic of Case Study 1 mapped out within TESLA™..... 139
Figure 31: illustrating the logic of Case Study 3 mapped out within TESLA™..... 140
Figure 32: illustrating the logic of Case Study 2 mapped out within TESLA™..... 141
Figure 33: Ratio plot illustrating the difference when recipient's receptivity is accounted for (a) and when it is not accounted for (b). 142
Figure 34: Connected account of the logic initial model..... 149
Figure 35: Screenshot of the user interface, illustrating how dropdown menus of permitted different levels of intensity to characterise each scenario. 152
Figure 36: Levels of intensity available for characterising uncertainty 153
Figure 37: Levels of intensity available for characterising recipient's positive and negative prior knowledge. 154
Figure 38: Values effect, by generating a random number between 0 and 0.45, 0.45 and 0.55, and 0.55 and 1 155
Figure 39: Levels of intensity available for characterising each personality trait..... 155
Figure 40: Example spreadsheet used within the initial model to characterise the nuclear waste disposal case study. Illustrating how each column represented a parameter used to calculate recipient's receptivity (contained in the last column on the right). 157
Figure 41: Mean recipient's receptivity after being calculated 10,000 times within 13 scenarios, with error bars representing standard deviation..... 159
Figure 42: Connected account of the logical way the dynamic model of recipient's receptivity was modelled within Microsoft Excel using VBA code. 162
Figure 43: Main simulation run setting out the logic of the dynamic model of recipient's receptivity 163

Figure 44: Process describing the logic supporting the process by which the recipient and provider engaged in dialogue over the sufficiency of submitted evidence..... 169
Figure 45: Logic sequence of events explaining how the agent's personal information was updated. 170
Figure 46: Screenshot of an agent's storyboard, in which values representing belief for, against and uncommitted and levels of positive and negative knowledge were randomly generated for ten lines of evidence. 172
Figure 47: Logic that describes the confidence building exercise. The agent's questions asked sequentially in a clockwise order, starting with the provider. 176
Figure 48: Method used to calculate the relative weight that the recipient assigned to each type of evidence being brokered. 177
Figure 49: Table used in the "Agent environment" spreadsheet to calculate recipient's receptivity. 178
Figure 50: Propensity to trust calculated using the negotiator, aggressor, submissive and avoider type of personality. "Avoider high" and "Avoider low" refer to the avoider type personality with high and low measures of extroversion. 187
Figure 51: Trustworthiness calculated using the negotiator, aggressor, submissive and avoider type of personality. "Avoider high" and "Avoider low" refer to the avoider type personality with high and low measures of agreeableness. 188
Figure 52: Referent power calculated for the four different personality types 189
Figure 53: Motivation to process evidence calculated for agents with low and high measures of openness in the presence of low and high uncertainty. 190

Figure 54: Motivation to share knowledge calculated for interacting agents that are equally motivated and those that have an opposite motivation to process the evidence. 191

Figure 55: Recipient's willingness to engage in dialogue based on updates to their positive and negative prior knowledge. 191

Figure 56: Confidence gained over multiple submissions of evidence in the "Worst case" 194

Figure 57: Confidence gained over multiple submissions of evidence in the "Best case" 195

This page is intentionally blank

LIST OF TABLES

Table 1: Case studies considered as potential candidates..... 73

Table 2: Applicable actions for the Defra receiving and passing-on of evidence and knowledge at each stage of the decision, as described by the respondent..... 126

Table 3: Applicable actions for the FSA receiving and passing-on of evidence and knowledge at each stage of the decision, as described by the respondent..... 127

Table 4: List of parameters used to calculate recipient's receptivity within each scenario 150

Table 5: Relative levels of intensity (low, medium and high) assigned to each personality type, where "Random" refers to when the level of intensity were selected at random. 166

Table 6: Levels of intensity reflecting likelihood that submissions of evidence will imbue the recipient with positive or negative prior knowledge, based on the type of provider submitting the evidence. 167

Table 7: "Best" and "Worst" case scenarios for different personality types..... 193

This page is intentionally blank

LIST OF ABBREVIATIONS

ABSM	Agent-based simulation modelling
AHP	Analytical hierarchical process
BBN	Bayesian Belief Network
CAS	Complex adaptive system
CBA	Cost Benefit Analysis
CEA	Cost Effectiveness Analysis
CO	Certainty Orientation
CRA	Comparative risk assessment
DOE	Direction of evidence
ESL	Evidence support logic
EMO	Evolutionary Multi-objective optimisation
ESL	Evidence support logic
IPT	Interval probability theory
LOE	Lines of evidence
MCA	Multi-criteria analysis
PCSC	Post-Closure Safety Case
RA	Risk assessment
RC	Risk characterisation
RIA	Regulatory impact assessment
UO	Uncertainty Orientation
VBA	Visual Basic Application
WOE	Weight of evidence

This page is intentionally blank

Chapter 1

INTRODUCTION

1.1 Chapter structure

This chapter provides an overview of the research project. Section 1.2 explains the background to the research; and Section 1.3 introduces the problem.

1.2 Background to the research

Government decision-making is undergoing a revolution in the UK. Proposals for modernising Government in the 1990s (Cabinet Office, 1999) are now being delivered through both Government programmes and legislation on 'better' and 'risk-based' regulation (Hutter, 2005). The premise is that a step change can be delivered, with risk-based regulation getting smarter, through an increased focus on high risks and decisions becoming more open to external scrutiny and challenge. Alongside, we observe a renewed emphasis being placed on the role and use of scientific advice in government decision making, amid a climate of low public trust in policy decisions. These combined initiatives challenge our understanding of the technical, political and psychological features of decision making on risk, particularly in the regulatory, environmental planning and policy development context.

In the UK substantive work has been carried out on the handling of risk and uncertainty to facilitate better risk-based regulation. At a minimum, risk-based regulation consists of using technical risk-based tools that have emerged out of economics (e.g. Cost Benefit Analysis) and science (e.g. risk assessment techniques) (Hutter, 2005). In a bid to secure a level of objectivity and transparency Government departments and agencies have published risk management frameworks that set out the technocratic processes of risk assessment, management and options appraisal that each department and agency undertakes (Strategy Unit, 2002; OXERA, 2000). Together these frameworks explain how power and responsibility is delegated from central Government to inform environmental planning and regulatory decisions (Figure 1a) and how information (robust evidence) is secured, evaluated, utilised and filtered back up, to inform further policy development (Figure 1b). However, there is a view that these frameworks fail to account for the complexities and nuances that characterise risk-based decision-making, despite the apparent objectivity and transparency (OXERA, 2000).

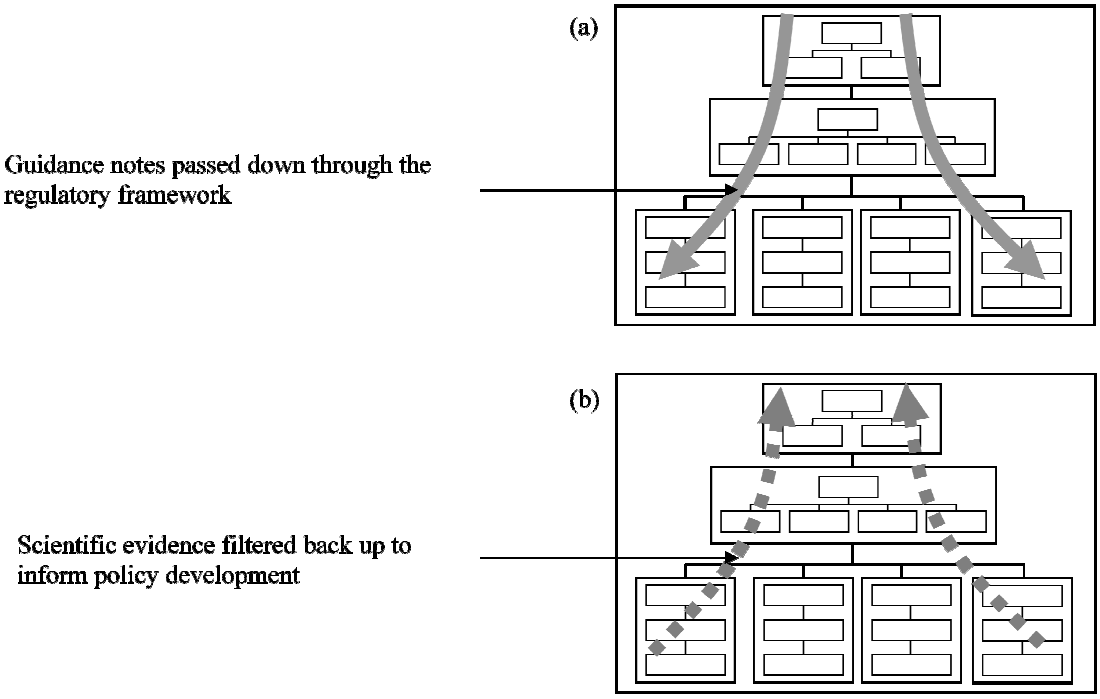


Figure 1: Simplified illustration how power and responsibility are delegated from central Government to its departments and agencies, (a) and information (robust evidence) is filtered back up to inform further policy development (b).

Conventional risk-management frameworks marginalise the transparency of risk-based regulation because they struggle to account for the handling of uncertainty and subjectivity that characterise the brokering of evidence (OXERA, 2000; Powell 1999). These frameworks set out the technocratic processes of risk assessment, management and options appraisal that each department and agency undertakes (Strategy Unit, 2002; OXERA, 2000; Cabinet Office, 1999; ILGRA, 1998). However, scientific evidence is often missing and/or contradictory, requiring practitioners to make value judgements in the face of manifold uncertainties.

Both theoretical models and extensive empirical testing exist to explain how individuals make decisions under uncertainty. The more recent and sophisticated of these models (e.g., Cumulative Prospect Theory; Tversky and Kahneman, 1992) imbue individuals with a rich set of psychological traits, which interact in complex ways when determining the actual choices made, including attitudes to losses versus gains, attitudes to certain outcomes, and psychological distortions of probability. Similarly, through behavioural game theory there is a wealth of knowledge on how humans make choices in strategic environments where the outcomes are affected by the choices of others (e.g. Camerer, 2003). However, the timing and length of risk-based regulation often means it is impossible to validate the impact participants have in 'real time'.

Agent-based modelling and simulation has the potential to go beyond conventional modelling and to help better understand the influence individuals have on the brokering of evidence in risk-based regulation. Conventional modelling characterises the equilibrium of a system, whereas agent-based modelling uses simple rules to generate complexity and a rationale for the emergence of behaviour. Understanding of individual agents and the diversity, connectedness and level of interaction between agents can be used to test how changes in agent behaviour may affect the emergence of a decision outcome.

This thesis uses the concept of agent-based modelling to capture the different shades and intricacy of risk-based regulation. It provides further insight into the transparency of a current real-world policy development (recommendation for a reduction in dietary salt intake), environmental planning (the disposal of avian influenza infected animal

carcasses) and regulatory decision (the review of a post-closure safety case for nuclear waste disposal). A critical review of existing knowledge and in-depth interviews with experts captures the structure of the case studies decision frameworks, decision protocols and known power and personality influences. This provides a foundation on which to develop an agent-based model. Development of such a model promises to explain the effect that power structure and personality may have on the brokering of evidence and that confidence building characterises risk-based regulation.

This page is intentionally blank

Chapter 2

RESEARCH AIM AND OBJECTIVES

2.1 Chapter structure

This chapter sets out the research aim and objectives of this project. This is complemented by an overview of the thesis structure, followed by an explanation of the research deliverables.

2.1.1 Research aim

The aim of this research was to provide a richer description of the brokering of scientific evidence in risk-based regulation by focusing on the social science aspects of decision-making.

2.1.2 Research Objectives

To achieve this aim the objectives of the research were to:

- Model government risk-based regulation by examining real-world case studies;
- Develop a research framework capable of mapping out the logic of the brokering process;
- Investigate how agent-based techniques might represent interacting decision makers;
- Investigate if the decisions reached are stable by assessing their sensitivity to changes in system parameters;

- Investigate if the automated decision making system is able to reach the same decision as those provided in three real-world case studies.

2.2 Thesis structure

This thesis explores the possibility of simulating risk-based regulation by, utilising agents (people) within a computer simulation environment. To this end, the author has investigated how power structure and personality may influence the confidence agents attached to submitted evidence. Explored the dynamics process in which evidence is brokered in risk-based regulation. Selected three case studies (representing policy development, environmental planning and regulatory permitting), which characterise the breadth of conditions under which evidence is brokered. By applying agent-based techniques, this information formed the foundation of a two-agent simulation environment. The resulting system resulted in emulating the brokering process that characterise confidence building in each case study, by calibrating parameters relating to decision context and attributes of the agents' character. The following ten chapters encapsulate this.

Chapter 1: Introduction - presents an overview of the research background and a rationale for carrying out the research.

Chapter 2: Research Aim and Objectives – presents a statement of the aim and objectives of the research project.

Chapter 3: Literature review - offers a critical review of the available literature and a summary of existing gaps in knowledge.

Chapter 4: Research methodology - provides a rationale for the chosen research methodology and a specification of the research method.

Chapter 5: Exploratory stage – explains the themes identified by carrying out in-depth unstructured and semi-structured interviews.

Chapter 6: Descriptive stage - explains the development of the research framework.

Chapter 7: Model development - draws on earlier work carried out, and explains the development of the agent-based model for illustrating the influence of power and personality on the brokering process.

Chapter 8: Proof of concept - presents the resulting agent-based model, insights generated and details about the validation and verification of the developed model.

Chapter 9: Discussion - discusses results and relative success of the research project focusing specifically on key intellectual insights, by placing them in context of prior-art.

Chapter 10: Conclusion – concludes how well the developed agent-based model met the research aim and objectives

2.3 Research deliverables

The thesis presents the development and application of a two-agent model that is capable of simulating the influence power structure and personality have on the brokering of scientific evidence in risk-based regulation. This provides a theoretical perspective with regards to the influence the brokering of evidence has on confidence building in risk-based regulation. The value of the model lies in its ability to replicate real-world decisions. Specifically, it provides a means of simulating real-world two-person interactions that encapsulate the dynamics of a regulator/applicant relationship. This is demonstrated in the context of three real-world case studies (policy development, environmental planning and regulatory decision), which represent the breadth of conditions under which scientific evidence is brokered in risk-based regulation.

This page is intentionally blank

Chapter 3

LITERATURE REVIEW

3.1 Chapter structure

This chapter provides a critical review of the literature relating to this research project and a presentation of identified gaps in knowledge. It asserts that there are considerable gaps in knowledge regarding the influence that decision participants have on risk-based regulation through their brokering of scientific evidence.

Section 3.2 describes the objective and method used for conducting the literature review. Section 3.3 describes risk-based regulation and addresses the issue that regulators face, regarding the disparity and complexity of environmental risk. Section 3.4 introduces the brokering of scientific evidence. Section 3.5 provides a critical review of the potential influence that power and personality has on the brokering of evidence. Section 3.6 introduces agent-based modelling and simulation. Section 3.7 explains the scope that existing agent-based models have for modelling the brokering process and the confidence building exercise that characterises risk-based regulation. Finally, Section 3.8 provides a summary of the identified gaps in knowledge.

3.2 Objective and methods used for conducting the literature review

The purpose of carrying out a structured critical review of existing literature was to identify gaps in knowledge regarding the influence social science aspects of decision making (specifically power and personality) have on risk-based regulation (i.e. policy development, environmental planning and regulatory decisions).

The initial approach was to carry out a 'key-word' search to understand how previous researchers had positioned themselves in relation to the problem. Relevant research was abundant, yet poorly synthesized and spread across a number of different disciplines. Throughout the review, a comprehensive search of both primary and secondary sources of emerging ideas from published and 'grey' literature was carried-out using academic databases and paper alerts. Databases consulted included: Scopus; Science Direct; Web of Knowledge; Emerald; and PsycInfo, in addition to a number of authoritative reviews located on the Internet. After reviewing the output, the author selected the most appropriate material for in-depth reading. This search strategy allowed the research perspective to expand into many different fields; for example, the value that different theoretical and methodological approaches have for describing how individuals make decisions under conditions of uncertainty. Identified gaps in knowledge were then placed in context of the current capacity of risk-management frameworks, published by government departments and agencies.

3.3 The disparity and complexity of risk-based regulation

This section summarises the issues associated with risk-based regulation and the risk management frameworks that are used to represent (or model) Government decision making.

Government departments and agencies have the remit of carrying out environmental decision making, with the aim of providing an improved resilience against environmental threats for current and future generations (Pollard et al., 2008). Environmental decisions are fundamentally about balancing risk and reward; loss versus gain (Pollard et al., 2008). Decision makers must cope with long gestation periods for risks (Power and McCarty, 2006), such as contamination exposure and cancer, establish clear casual relationships (e.g. between greenhouse gases and climate change) and manage controversies over tradeoffs that require weighing risks and benefits against each other (e.g. agriculture production and the use of pesticides). In addition, the vast number of intervening variables, which exist between a cause and effect of environmental harm subtracts from the amount of available evidence required to manage risk. This omnipresence of imperfect information means that zero risk is unobtainable and the need to cope with uncertainties is inevitable (Power and McCarty, 2006).

During the 1980s and 90s, there was a call for Government to acknowledge uncertainties in their decision-making. The public lost confidence in conventional regulatory models and called for the adoption of the precautionary principle based on

the belief that poorly understood risks remained unregulated (Hutter, 2005). This together with the call for Government to do "more for less" (Hutter, 2005) has rendered conventional command-and-control regulation (NRC, 1996; Presidential commission, 1997) inappropriate for environmental decision making. Critics claimed conventional regulation was resource intensive and overly prescriptive (Kirk et al., 2005), potentially inhibiting innovation and the development of new technologies (Wiener, 2004). In addition, Hampton (2005) claimed conventional regulation created an unfair competitive advantage by paying inconsistent attention toward regions and areas, reducing the benefit regulatory resources can bring by increasing administrative burdens needlessly. The Government's response to such criticism has been a strong deregulatory rhetoric, centring on alleged overregulation, legalism, inflexibility and an alleged absence of attention being paid toward the cost of regulation (Hutter, 2005).

Regulators are responsible for administering regulation by implementing it through a framework of due process and legislative documents (acts, regulations, annexes, statutory guidance). Within Europe, European Community (EC) institutions set the framework of Council legislation upon its Member States. Directives are the chosen legal instrument in the environmental arena because of the greater flexibility they offer, allowing more room for interpretation (Bell and McGillivray, 2000). Acts of Parliament (primary legislation) and delegated legislation (secondary legislation) transpose Directives into national law (Bell and McGillivray, 2000) and regulation acts as administrative arms of the state. Government departments and agencies responsible for administering regulation, supervise the regulated community through performance

measures and feedback provides Government with market signals of acceptable behaviour (Blackman, 1998).

Today, proposals for modernising Government in the 1990s (Cabinet Office, 1999) are now being delivered through Government programmes of work and legislation on 'better' and 'risk-based' regulation (Strategy Unit, 2002; Hampton, 2005; Hutter, 2005; Pollard et al., 2008). The premise is that there can be a step change in decision quality from the regulation of occupational and public safety risks, to the safety of the food chain and the environment by allocating regulatory resources in proportion to the risk and interventions they require (BRC, 2006; Environment Agency, 2005; Hutter, 2005). Essentially this entails focusing on higher risks with decisions being more open to external scrutiny and challenge. This promises improvements but at the cost of interventions requiring controversial tradeoffs involving conflicting and competing objectives (Long and Fischhoff, 2000). To account for this, there has been a renewed emphasis placed on the value of scientific evidence in Government decision making, set within a historic climate of low public trust (Powell, 1999; House of Lords, 2000; House of Lords, 2006). Combined, these initiatives require an understanding of the technical, social, political and psychological features of decision making, which in practice is a highly complex issue, fraught with uncertainty.

The primary source of uncertainty in risk-based regulation is the absence of evidence and/or the presence of contradictory evidence (Hutter, 2005; Powell, 1999). In an attempt to better understand uncertainty, scholars have developed a number of typologies (e.g. Morgan and Henrion, 1999; Smithson, 1989). Stirling (1999; 2003), for

example, defines risk in terms of probabilities and consequences, divides uncertainty into *stochastic uncertainty* (good knowledge of both probabilities and consequences), *ambiguity* (good knowledge of probabilities and poor knowledge of consequences), *classical uncertainty* (poor knowledge of probabilities and good knowledge of consequences) and *ignorance* (poor knowledge of both probabilities and consequences). In the context of risk-based regulation, Stirling's typology of uncertainty has the potential to explain spurious precision, controversy over interpretations of expert findings, difficulty in planning and the occurrences of unwanted surprises, respectively (Andrews et al., 2004). From a less technical perspective, however, Morgan and Henrion (1999) suggest more attention should be paid towards *expert uncertainty* and *linguistic imprecision*. In addition, Boholm (2003), assuming uncertainty is the part of risk that cannot be calculated, suggests that practitioners wishing to manage risk should think of uncertainty in terms of coping strategies, such as faith, precaution and avoidance. Hence, suggesting that uncertainty is not just a product of absent and/or contradictory evidence but also of subjective value judgements being made regarding the direction, strength and weight of evidence that supports the assessment and management of risk.

The UK Government has carried out substantive work on the handling of risk and uncertainty (e.g. OXERA, 2000; Strategy Unit, 2002, POST, 2004). Much of this work has placed an emphasis on the value and construct of scientific evidence (Science Advisory Council, 2006; Bradshaw and Borchers, 2000). Her Majesty's Government, for example, have published guidance emphasising the need to secure a wide range of advice from the best sources, whilst recognising that the correct balance of

interdisciplinary advice will depend on the issue in question (HM Government, 2005). Moreover, it sets out the importance of making the use of evidence transparent, so that decisions can withstand the challenges of credibility, reliability and objectivity.

In an attempt to provide a measure of transparency and objectivity, Government departments and agencies have published risk management frameworks. These frameworks set out clearly an agency's or department's approach toward their assessment and management of risk and option appraisal. Current frameworks successfully provide a technical schematic of information flows and accountabilities. They act as a guide for onlookers, demonstrating the procedure followed to assess and manage risk. The risk management framework published by DETR (2000), for example, clearly sets out the importance of addressing the issue of "risk of what to whom?" (Figure 2). It emphasises the need to continually revisit the risk and ask whether there is need to allocate more learning resources, by advocating a tiered approach (the screening, prioritisation and qualitative treatment of risk in advance of quantitative treatment of risk). It also demonstrates the importance of assessing environmental risk alongside economic, social, technical and management issues. Hence, risk management frameworks transparently set out the technocratic processes of ensuring regulatory resources are targeted and proportionally allocated (Strategy Unit, 2002). However, risk management frameworks do not account for the influence that personal or organisational features play in these decisions.

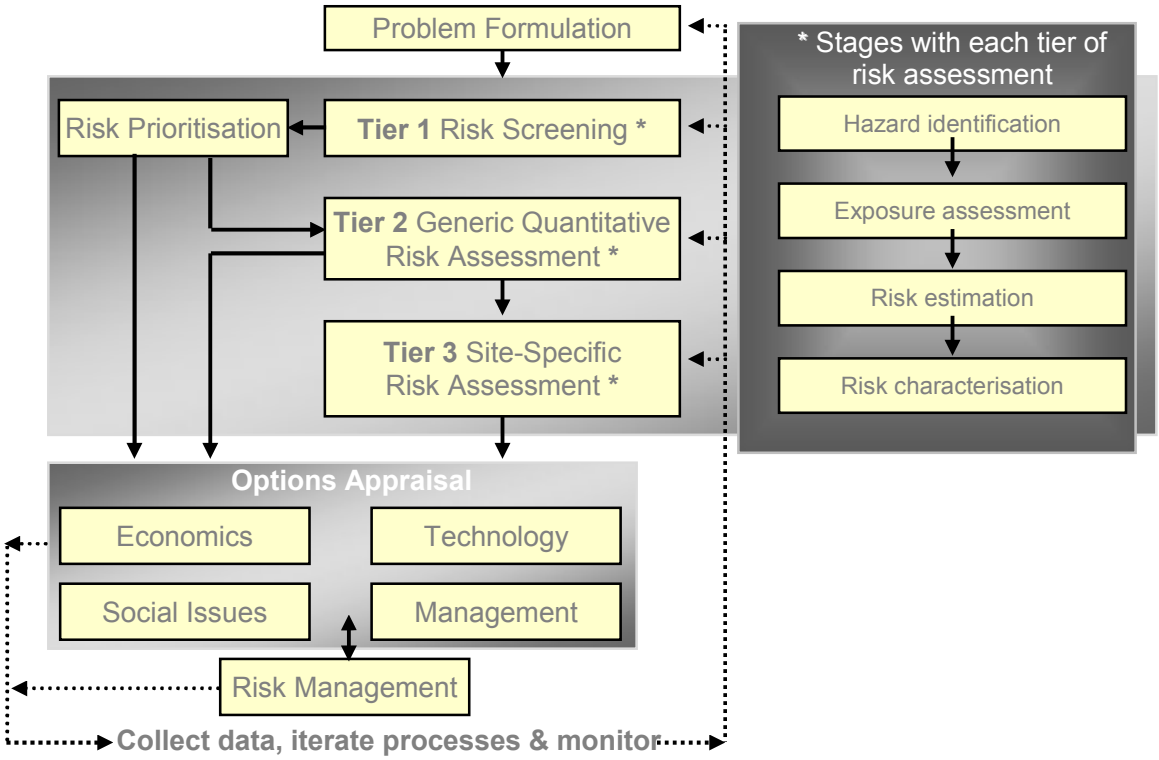


Figure 2: Risk management framework (After DETR et al., 2000)

Risk management frameworks published by Government departments and agencies pay little homage to the fact that decisions made are acted upon by people. As such, there remains a view that current risk management frameworks and processes fail to capture fully the complexities and nuances of decision making in risk-based regulation (RCEP, 1998; Powell, 1999; Slater et al., 2006).

Incomplete evidence, emphasises the influence practitioners have on the final decision outcome, and the amount of resources that should be spent to assess and manage the risk. As it stands, current frameworks suggest that risk management decisions are one dimensional, which of course is not true. Decision makers are often required to engage in extensive dialogue with decision-participants, spread across a number of different

domains. There are a vast number of personal and organisational features that are known to influence decisions on risk. Figure 3 illustrates the type of personal and organisational features that are known to influence risk decisions.

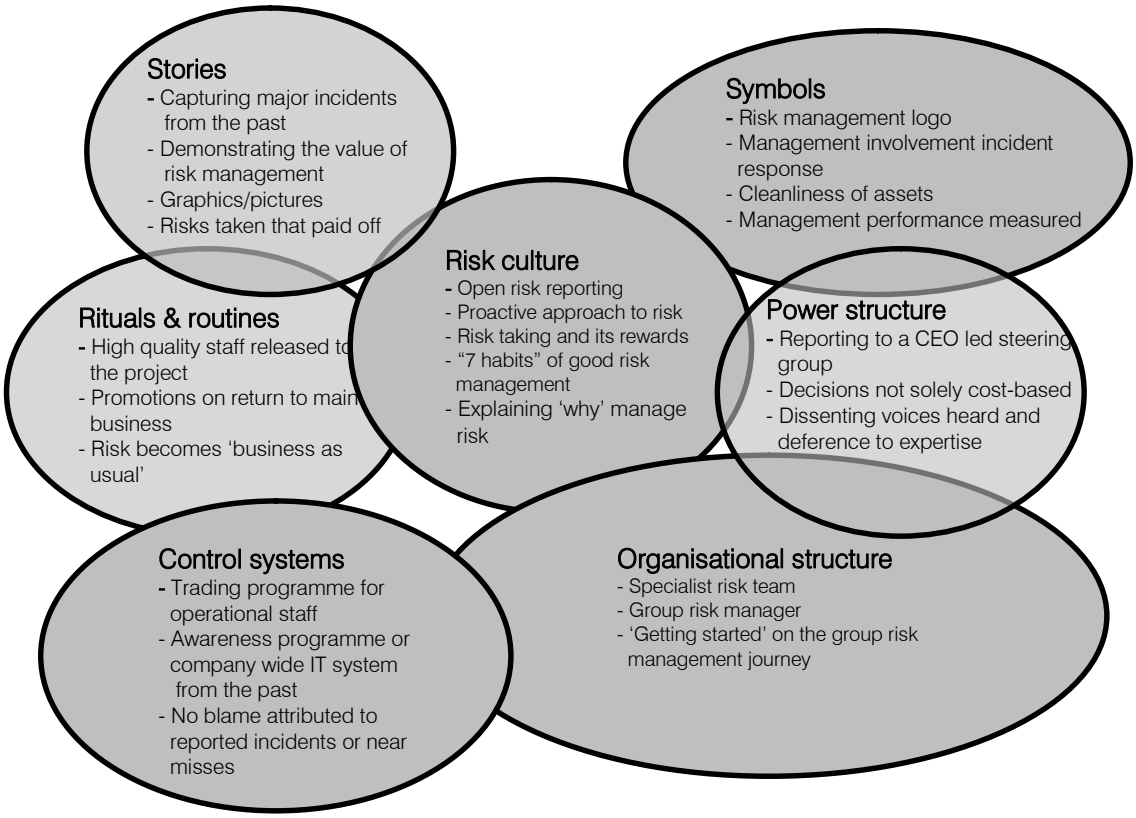


Figure 3: Personal and organizational features that influence risk-based decisions (After Johnson, 1992; Content, 2005).

In summary, the handling of risk and uncertainty is an important issue, one that has received much attention in recent history. It still remains an issue for modern regulation. This section has summarised the issues associated with risk-based regulation and the transparency of current risk-management frameworks used to represent Government decision making. Risk-management frameworks have been developed to represent how governments make decisions under conditions of risk and uncertainty. Departmental

risk-management frameworks explain how the delegation of authority and the elicitation (and use) of scientific evidence and knowledge informs policy development, environmental planning and regulatory decisions. They explain how Government departments and agencies manage the risks to the delivery of strategic objectives. They set out the framework in which participants collaborate and summarise how science is incorporated (NAO, 2000). Yet, there remains a view that current frameworks fail to capture the complexities, realities and nuances of decision-making beyond a technical schematic of information flows and accountabilities (Powell, 1999; OXERA, 2000). The following section discusses the brokering of the scientific evidence that support decisions on risk in risk-based regulation.

3.4 The brokering of scientific evidence in risk-based regulation

Risk characterisation (a statement on the significance of a risk and its attending uncertainties) has been described as the most fundamental aspect of risk management, allowing the development of feasible options for abating risk (Deisler, 1988). What can meaningfully be said about the significance of a risk fundamentally depends on the extent and quality of the scientific evidence that underpins the analysis, and ones' confidence in it. In practice, scientific evidence is brokered between many actors (or 'agents'), in the decision. That is, research is often:

- procured or elicited from the research base;
- used alongside targeted, site-, or policy-specific studies;
- used to develop new lines of evidence that may support or contradict an existing line of reasoning;

- applied to develop an overall weight of evidence about a risk decision – for example, whether or not to extend an environmental permit, for an integrated petroleum refinery; and
- used to produce guidance, for example on the consumption of alcohol within certain ‘safe’ limits.

Figure 4 is a generalised summary of the key actors involved in the regulatory review of a post-closure safety case used to support the decision on whether (or not) to reauthorize disposals at a pre-existing radioactive waste repository in the UK (after Yearsley et al., 2001). In practice, this decision involves inputs from fundamental and applied scientists, scientific consultants, highly specified domain experts, advisory committees, expert referees, various publics with local or specialist knowledge, industry sector specialists with their scientific advisors, technical policy development specialists and others. These actors interact and share evidence and knowledge, forming various lines of evidence about the risk in question.

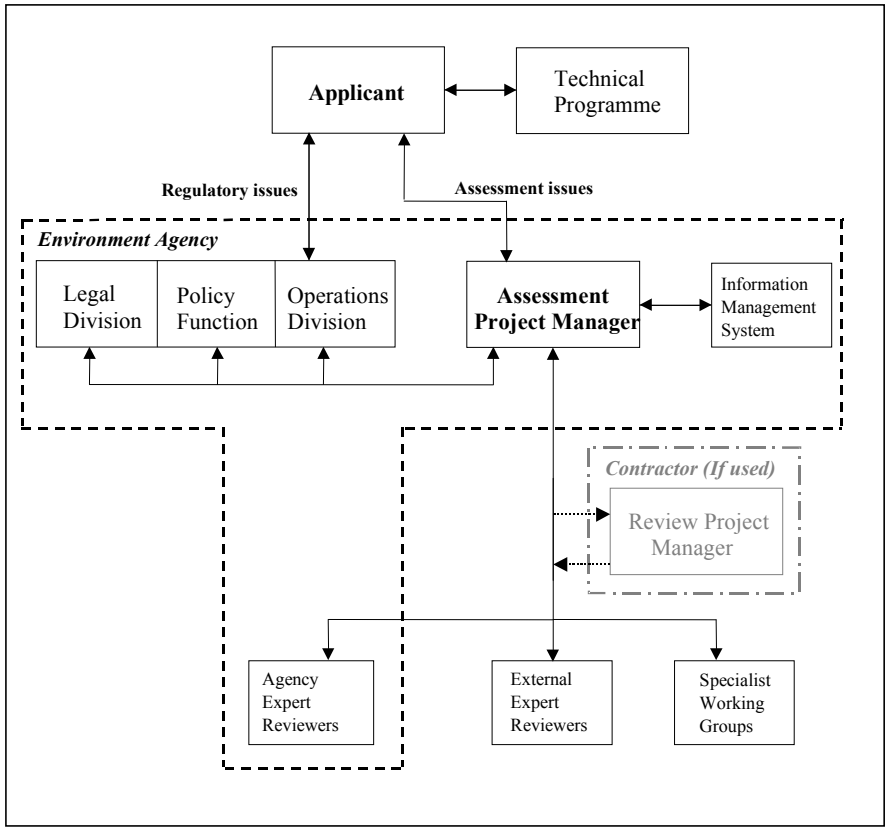


Figure 4: An example structure of the institutional sub-components involved in the decision on reviewing post-closure safety cases. Individual boxes are often populated by an array of domain experts. In this case, representatives of the regulator's policy function make recommendations to the Government Department and ultimately the Secretary of State regarding the re-authorisation of a facility (adapted from Yearsley et al., 2001).

Lines of evidence informing environmental decisions rarely point in the same direction (i.e. are rarely universally supportive of a particular hypothesis), come in various strengths (of evidence), and thus require synthesis so an overall weight of evidence can be applied to the characterisation (significance and confidence) of the risk (e.g. Lowell et al., 2000; Pollard et al., 2008). Moving from the bottom to the top, Figure 5

illustrates how different sources of primary scientific evidence (e.g. experimental or field data) inform related sources of knowledge (e.g. the predicted future behaviour of contaminants once discharged to an aquatic environment) on a specific issue (e.g. the risk of harm to a specific ecosystem). These are presented, in concert and through a sequence of individual transactions between agents (people), to an ultimate decision maker for an assessment of the significance of the risk and consequently a decision whether to accept the risk or not and how to manage it.

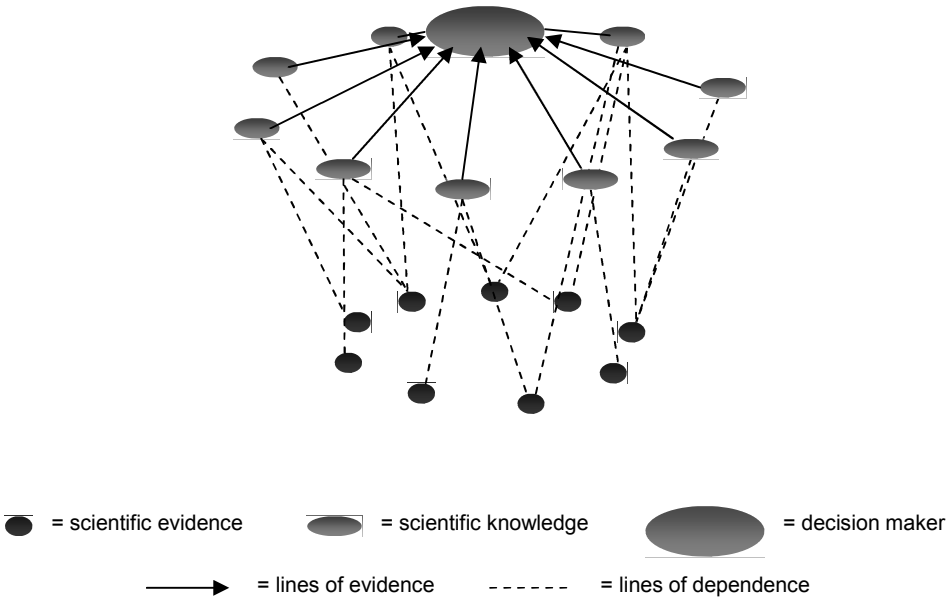


Figure 5: A conceptual simplification of the brokering of evidence and knowledge.

The brokering of scientific evidence and knowledge in support of risk assessments is inherently uncertain due to information gaps, the existence of competing theories and the presence of manifold uncertainty (Powell, 1999). Risk-informed decision-making is value-laden, not least because decision participants (agents) make value judgements regarding the sufficiency and credibility of available information. Moreover,

individuals do not make stable decisions under uncertainty, as all decisions made are to some degree biased by participants' perceptions of the decision environment (Slovic et al., 1982; Slovic, 2000). Furthermore, risk characterisation itself requires a discussion of values with a pre-requisite discussion of risk appetite (Tuler et al., 2005). Under these conditions, unfettered assessments of the direction, strength and weight of evidence that constitute a view of the risks, may not be possible. Current technocratic risk-management frameworks fail to account fully for this and so may compromise the level of openness and transparency that they attempt to infer.

The discussion that follows attempts to provide a richer description of this brokering of scientific evidence and knowledge in risk-based regulation**.** Evidence is referred to as 'raw data' and knowledge as 'interpretations' that inform an assessment of the significance of the collective evidence in the context of the risk question being posed**.** For example, environmental regulatory officials must frequently evaluate the risks posed by a new operational plant or changes to plant design and/or layout. A regulatory officer may need to decide, for example, on the reliable performance of an in-plant wastewater treatment plant for the biological treatment of pharmaceutical residues in process streams. Often the operator and their professional advisors (environmental consultants, say) will supply this data and the risk assessment, in support of a modification to the plant. The regulator must process the evidence on the treatment performance of the individual unit, for example, to evaluate the risk of exceeding environmental quality standards, and then use it to establish compliance criteria in consultation with the operator.

Figure 6 illustrates a typical process associated with the brokering of evidence and knowledge. Here, nodes represent an individual agent in the decision. Agents must receive (●), process (■), and pass-on (▲) evidence and knowledge. If the two nodes at the bottom represent an operator and a consultant, the square dotted arrows can represent the evidence they gather. If the node at the top of this figure represents a regulatory officer (decision maker), the solid arrows can represent the scientific knowledge and evidence presented to the regulator, after the operator and consultant has placed the evidence in context of the risk question being asked. The round dotted arrows represent the outcome, i.e. the confidence the regulator has in approving, for example, the authorisation of an environmental permit.

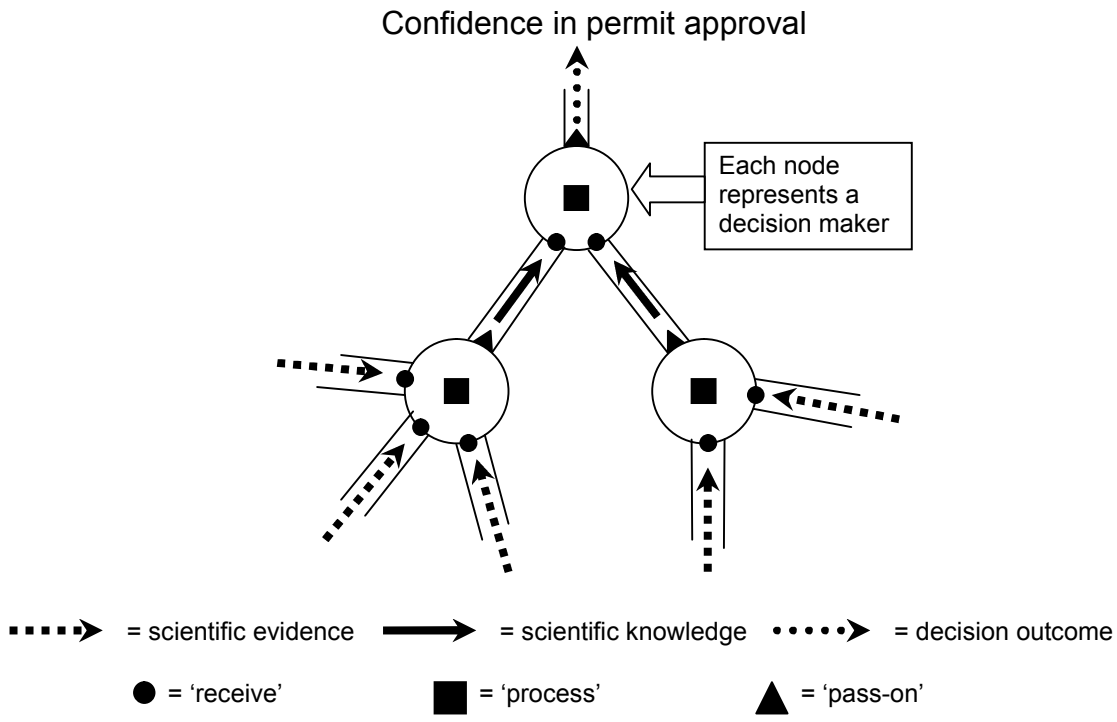


Figure 6: The receiving, processing and passing-on of evidence and knowledge.

To facilitate the division of expertise and responsibilities, government have often assumed they can handle uncertainties in decisions in the vacuum of science (Mayo and Hollander, 1994). However, this is an unrealistic perspective because real world decisions are subject to both fraud and mistakes (e.g. Mayo and Hollander, 1994). In reality, decision makers must determine how sufficient evidence and knowledge is for answering a pertinent question. Sufficient options are those whose outcomes have an "acceptable" value (Mayo and Hollander, 1994). Of course, this requires the ability to determine the level of acceptability, which is not easy for a regulatory officer faced with a high degree of decision uncertainty.

Figure 6 sets out the logic of approach but not the reality that at each step a recipient may wish to reject the scientific evidence and knowledge provided. It does not illustrate how the lack of evidence and/or the presence of contradictory evidence can increase decision uncertainty and the level of subjectivity required to make decisions. It does not illustrate the extent that value judgements made by the recipient can determine the sufficiency and dependency of different sources of scientific evidence and knowledge. To address this, later sections of this thesis critically assess how a decision maker's personality and position within a power structure may determine whether an agent will engage in dialogue and whether this is likely to be conducive to the resolution of decision uncertainty and confidence that there is sufficient evidence to support (or refute) the risk question being posed.

3.5 Power & personality

Scholars have already reported on how individuals make decisions under uncertainty, through both theoretical models and extensive empirical testing. This section discusses the potential influence that power and personality have on the brokering of scientific evidence and knowledge; the confidence building exercise that characterises risk-based regulation.

3.5.1 Influence of power

Power is the ability to control one's environment and the behaviour of those within it (Dahl, 1957; French and Raven, 1959; Kanter, 1979). In the context of brokering evidence and knowledge, power is realised by an individual's capacity to include or exclude information, contingent on their view of its validity and relevance to the decision being considered. The distribution of power can be perceived as a power structure embodying the influences people have by reference to their status and the period in which they hold power.

Substantial literature exists on the dynamics of power (e.g. French and Raven, 1959; Morgan, 1986; Paton, 1984; Stephenson, 1985; Liao, 2008a; 2008b). French and Raven (1959) advanced a taxonomy of five forms of power (legitimate power, referent power, expert/informational power, reward power and coercive power). These describe the sources of power that a participant may have access to, and the influences they hold within a power structure (Belaya et al., 2008). French and Raven's (1959) five forms of

power can be considered to relate to a decision participant's ability to receive, process and pass-on scientific evidence and knowledge, as demonstrated in Figure 7.

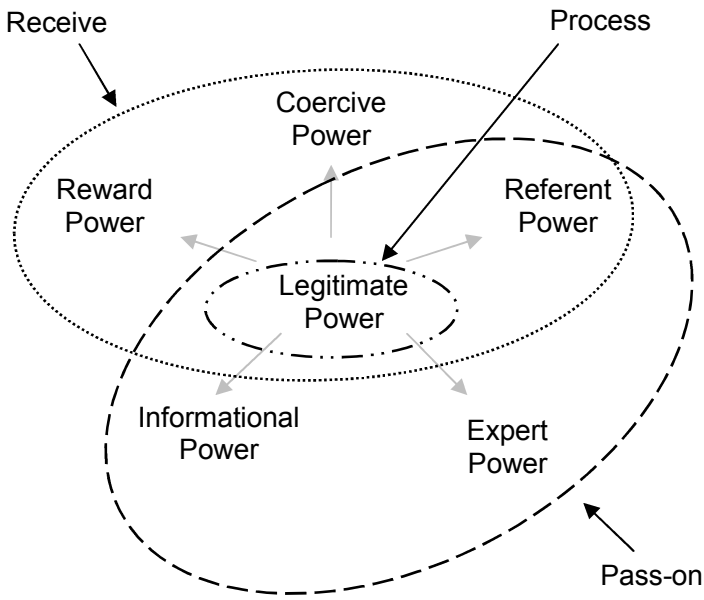


Figure 7: French and Raven's (1959) five forms of power related to the brokering of evidence and knowledge in risk-based regulation.

This taxonomy plays out in authentic policy, environmental planning and regulatory decisions as the various agents in the decision exchange sort and validate evidence in support of risk characterisation. The first aspect of an agent's power to influence the brokering process is their ability to 'receive' scientific evidence and knowledge, and relates to their legitimate power. Legitimate power, usually equated with authority, refers to an individual's position within a power structure (Handy, 1999). The power resides with the position held, rather than with the individual (Belaya et al., 2008). Here, the recipient agent has a legitimate right to influence and oblige others to comply with a course of action. For example, a regulatory inspector is legally empowered to

inspect and gather environmental compliance data. Legitimate power, however, is only as strong as it is supported, and additional 'guaranteeing' sources of power can reinforce it. For example, providing site inspectors with access to reward power, coercive power and referent power will strengthen their legitimate power.

Reward power is relevant to an individual's ability to offer an incentive (Belaya et al., 2008) and may be obvious in the case of an inspecting officer's ability to encourage the submission of compliance data. Less obvious might be the rewards offered for the delivery of timely information.

Coercive power is relevant to an individual's ability to punish those who do not comply. Although this may provide a regulator with short-term gains, it may also prove to be ineffectual in the long run (Rahim et al., 2001). In general, the expression of coercive power may result in resentment and resistance because it is fuelled by the respondent's desire for the reward and the fear of having it withheld (Molm, 1997). The mere perception that a recipient agent has coercive power may be sufficient to yield information. However, if abused coercive power can evoke conflict, resulting in a regulator being reprimanded, for example, via judicial review.

Referent power will also aid a recipient agent's capacity to receive evidence and knowledge. Referent power helps build compliance and in contrast to legitimate power, resides with the personality of the individual. It takes time to establish. For example, an inspecting officer that maintains a long-standing relationship with an operator will find it easier when they are required to communicate a sufficiently convincing reason

why the operator should comply with a specific request. If the officer is successful in establishing this relationship, they can be considered to hold a degree of referent power, thereby facilitating access to evidence and knowledge in support of a decision. However, if the relationship between an operator and an officer is brief and the officer has only a small window of opportunity to establish referent power, this opportunity may be lost. Hence, referent power is only as effective as the extent to which recipients become exposed to it.

The second aspect of an agent's power to influence the brokering of evidence and knowledge is their ability to 'process' it. Again, legitimate power is the first point of call. An individual's influence will depend on the extent their role allows, or expects them to partake in the gathering, processing, analysis, or third party review of evidence and knowledge. French and Raven's (1959) other four forms of power have minimal impact on a participant's ability to influence the processing of scientific evidence and knowledge.

The final aspect is an agent's ability to 'pass-on' the evidence and knowledge provided to them. The recipient agent becomes the provider as they 'receive and accept' information and pass it on to other agents in the decision process, usually labelled with some statement of its validity and/or their confidence in it. The ability to pass-on evidence is intertwined with the ability to receive it because power operates both relationally and reciprocally. For example, a recipient's legitimate power may allow them to reject information but whether this happens depends on whether they perceive the provider to have expert and/or referent power. Expert power, for example, can only

be inferred upon agents by those on whom it will be exercised, and must be explicitly and implicitly recognised to exist. As such, expert power is said to be the most socially acceptable form of power (Handy, 1999). Hence, placing this in the context of the brokering process, if a provider has expert power then it can be assumed that the recipients will be receptive to the scientific evidence and knowledge provided. However, if for any reason the recipient becomes aware of 'credibility gaps' associated with the evidence and knowledge provided to them, the provider's expert power can become discredited (Handy, 1999). When expert power is no longer perceived to exist in the providing agent, the recipient agent may reject the evidence and knowledge provided they have legitimate power in which to do so. Hence, a provider's ability to pass-on scientific evidence and knowledge will depend on whether the recipient is receptive.

In summary, the brokering of evidence and knowledge can be viewed as being mediated through a power structure, whereby agents with a range of interests have varying degrees of authority to determine the flow, acceptance and transfer of information to inform decisions on risk. The power relationships are designed to ensure the right people are best placed to exercise the correct level of power at the appropriate time. However, power requires a balance between parties, it operates relationally and reciprocally and it is subjective. It is not only dependent on whether the agent is in a position to have power, but also on whether they have sufficient personality, for example, to exercise referent power.

3.5.2 Influence of Personality

Personality research is concerned with the psychology of the whole person (Epstein, 1996). Insights from this field explain the influences that personality has on the brokering of evidence and knowledge, and on an agent's ability to uphold certain responsibilities for the processing of information under conditions of uncertainty and the required levels of interpersonal communication, especially trust.

One of the most popular measures of interpersonal processes has been the five-factor model of personality (Costa and McCrae, 1992). This has been accepted by scholars (Including Barrick et al., 1998; Denissen and Penke, 2008; Digman, 1990; Goldberg, 1990; Hong et al., 2008; John, 1990; John and Srivastava, 1999) and is said to encompass the most significant variations of human personality (Ivancevich and Matteson, 1999; Robbins, 2003). The model measures personality by reference to five personality traits (neuroticism, extroversion, openness to experience, agreeableness and conscientiousness); referred to as the 'big five' dimensions of personality. These are said to represent the characteristics of an individual that are reasonably stable over time (Costa and McCrae, 1992; Johnson, 1999), providing an aggregate descriptor of a person's typical behaviour.

Extensive studies have demonstrated how the big five traits relate to an individual's typical behaviour; for example in the workplace (e.g. Back et al., 2006; Berry et al., 2007; Burke and Witt, 2004; Flaherty and Moss, 2007; Lee et al., 2005). Personality traits differ from individual level states. Traits assess how a person is generally, whereas states refer to how a person is in the moment (Cattell et al., 1947; Fridhandler,

1986; Nesselroade, 1988; Schutte et al., 2003; Ten Berge and De Raad, 1999). In recognition of this, scholars such as Mischel (1968) have questioned the validity of focusing only on traits alone, suggesting that a greater emphasis should also be placed on the role that situational forces have on the emergence of behaviour (Mischel, 1968; Mischel, 1999; Shoda, 1999). These authors argue for characterising personalities by stable patterns of behaviour, and by distinct and stable patterns of situation-behaviour relations (Shoda et al., 2002). This combined *'if... then...'* approach has allowed researchers to create so called 'behavioural signatures' that are predictive of patterns of variability across different situations (Mischel, 1999; Mischel and Shoda,, 1995; Shoda, 1999; Shoda et al., 2002). This allows researchers to specify how traits play out with increasing precision under different situations (Ten Berg and De Raad, 1999). This person-by-situation approach has been the source of much debate (e.g. Bem, 1983; Blass, 1991; Bowers, 1973; Endler, 1984; Eysenck and Eysenck, 1980; Johnson, 1999; Reynolds and Karraker, 2003; Saucier et al., 2007; Shoda, 1999; Ten Berge and De Raad, 1999; Ten Berge and De Raad, 2002), with some questioning how valid and novel it really is (e.g. Funder, 1996; Johnson, 1999). That said, it has become increasingly popular within modern personality research, and scholars generally agree in the value of its approach (e.g. Borkenau et al., 2006; Fleeson, 2007; Graziano et al., 2007; Kammrath et al., 2005; Withey et al., 2005).

The aim of this work is to describe how distinct *if... then...* behavioural signatures might explain the influence personality has on the brokering of evidence and knowledge within risk-based decisions. To achieve this, the influence specific factors of the 'big five' have on the brokering process will be drawn upon, as it is referred to elsewhere in

the context of knowledge sharing (e.g. Bakker et al., 2006; Liu, 2008; Mooradian et al., 2006). Bakker et al. (2006) separate knowledge sharing into the phases of exploration and exploitation. The former describes the point at which agents discuss and work together to solve a problem; the latter describes the phase in which knowledge is integrated (Bakker et al., 2006). Analogously, the exploitation phase is referred to as the act of 'receiving and accepting' and the exploration phase as the act of 'engaging in dialogue'.

Research informs us of many factors that influence participants during the act of "receiving and accepting" and the act of "engaging in dialogue". For example, the numerous factors that affect knowledge sharing include: (i) the properties of knowledge (e.g. the degree of articulation and aggregation; Blacker, 1995; Nonaka and Takeuchi, 1995; Spender, 1996); (ii) organisational culture (Wasko and Faraj, 2005); and (iii) interpersonal relationships (Hansen, 1999; Levin and Cross, 2004).

The most common property referred to is the influence of trust (e.g. Abrams et al., 2003; Levin et al., 2006; Mayer et al., 1995; McEvily et al., 2003). Trust is indicative of a person's willingness to engage in sharing knowledge (e.g. Davenport and Prusak, 1998; Uzzi, 1997). Rotter (1971) defined trust as "*the generalized expectancy held by an individual that the word, promise, oral or written statement of another individual or group can be relied upon*". In its literal sense, trust is referred to as a recipient agent's belief that the evidence and knowledge provided is reliable and sufficient. Mayer et al. (1995) posited the "*higher a trustor's propensity to trust, the higher the trust for the trustee prior to availability of information about the trustee*", inferring that the

likelihood a recipient will 'receive and accept' evidence and knowledge will, in part, depend on the recipient's propensity to trust. However, propensity to trust is related to dispositional trust - the general willingness to trust others (Mayer et al., 1995), which is neither focused on specific others nor dependent on specific contexts (Mooradian et al., 2006).

Interpersonal trust, on the other hand, is a measure of how trustworthy participants perceive others to be. It is determined by the situation and is multi-dimensional (e.g. McAllister, 1995; Rempel et al., 1985; Abrams et al., 2003). Abrams et al. (2003) generally define interpersonal trust as "*the willingness of a party to be vulnerable*" (Dirks and Ferrin, 2001; Gambetta, 1988; Kramer and Tyler, 1996; Mayer et al., 1995), suggesting that participants display more interpersonal trust and knowledge sharing behaviour when they are more willing to accept vulnerability. In this regard, Evans and Revelle (2008) describe vulnerability as a ratio of costs (e.g. betrayal) and benefits (e.g. reciprocity) where the uncertainty over gains or losses motivates (or discourages) trusting behaviour. These authors also suggest that those with a propensity to trust are more inclined to establish interpersonal trust and engage in knowledge brokering and networking (Becerra and Gupta, 2003; Evans and Revelle, 2008; Swan et al., 2002 ref by Mooradian et al., 2006). Mooradian et al. (2006), for example, empirically linked propensity to trust to interpersonal trust 'down stream' in reports of knowledge sharing behaviour.

Studies have linked measures of the big five personality traits to trust and knowledge sharing (e.g. Evans and Revelle, 2008; Martins, 2002; Mooradian et al., 2006). Evans

and Revelle (2008) demonstrated that trust, rather than trustworthiness, predicted whether a recipient would return money in the standard economic investment game. They demonstrate that the tendency to 'trust' was positively correlated with extroversion and negatively with neuroticism, and that 'trustworthiness' was positively correlated with agreeableness and conscientiousness. Only agreeableness was related to the amount of money invested, with more money being invested under the send-only condition compared to the simultaneous condition. It was suggested that agreeableness motivated more interpersonal trust under greater levels of risk and uncertainty (Evans and Revelle, 2008), possibly motivated by the opportunity to cooperate rather than compete (Liao and Chuang, 2004). Hence, although propensity to trust may translate as a propensity to engage in interpersonal trust this will depend on whether the situational context motivates agents to do so.

Scholars explain that the uncertainty associated with the information being brokered will account for a large proportion of an agent's motivation. Hodson and Sorrentino (1999), for example, explain that uncertainty orientation (UO), and certainty orientation (CO), is based on a composite measure of a person's approach to uncertainty (need to master uncertainty; Sorrentino et al., 1992) and certainty (acquiescence-free measure of authoritarianism; Cherry and Byrne, 1977), allowing the person to deal with the complexities of information-processing. They suggest that individuals engage in more achievement related behaviour and systematically process information more when the situational uncertainty is low for CO and high for UO, and conversely engage in less achievement related behaviour and systematically process information less when situational uncertainty is high for CO and low for UO individuals. Investigating the

relationship with the big five personality traits, only openness to experience was found to be positively related to being uncertainty orientated. Therefore, suggesting that not only is a high openness to experience indicative of a person not fazed by uncertainty, but that given the choice, they are more likely to approach uncertainty in the hope of resolving it (Hodson and Sorrentino, 1999).

These studies suggest that it is possible to predict whether a recipient agent would be unwilling to "receive and accept" scientific evidence and knowledge without first engaging in dialogue by knowing whether:

- the level of uncertainty associated with the scientific evidence and knowledge motivates them to do so;
- they have prior knowledge that causes them to believe that the provider is trustworthy (e.g. having sufficient expert power); or
- they lack prior knowledge and have the propensity to trust.

Failing this, and assuming a recipient has sufficient legitimate power, an exploration phase would proceed the exploitation phase. During the exploration phase, propensity to trust, interpersonal trust, and willingness to engage in knowledge sharing behaviour will play a role. For risk-based decisions, the most enduring characteristic being brokered is the level of uncertainty associated with the evidence and knowledge. Personality research suggests that an agent's uncertainty orientation will in part determine whether they will be motivated to process information systematically and carefully. Cheung (unpublished) explains that recipients and providers should have opposite orientations if the aim is to share knowledge. In the context of the study

presented in this thesis, the recipient agent must determine whether they agree with the providing agent over the sufficiency of the evidence and knowledge. Unlimited time and resources might permit success to be measured in terms of how conducive this dialogue is to the resolution of uncertainty. However, limited time and resources may inhibit this from ever happening.

The literature presented in this section demonstrates how power and personality may affect risk-based regulation by participant's involvement in the brokering of scientific evidence and knowledge. That said, the contributions of power and personality, in psychological studies of group decision making are challenging to isolate in a real-world context. Construction of a virtual decision making environment, using the concept of "automated decision makers", however, permits scenarios to be simulated and explored, offering insights that are not practically possible by studying real time behaviour (e.g. North and Macal, 2007; Zhang and Zhang, 2007). In particular, agent-based techniques make it possible to model the complex interaction of effects that influence humans making decisions under uncertainty, whilst taking account of the behaviour of others.

3.6 Agent-based modelling and simulation

Agent-based modelling and simulation is currently providing new ways to view, understand and anticipate the likely effects of decision-making. Scholars have defined agent-based modelling as "*the simulation of actions and interactions of autonomous individuals with a view to assessing their effects on the system as a whole*" (North and

Macal, 2007). Agent-based modelling essentially consists of an artificial society where the coding of individual elements of that society makes it possible to simulate complex scenarios.

Agent-based modelling builds on techniques such as discrete event simulation and object orientated programming (Brailsford and Schnidt, 2003). Discrete event simulation provides an established mechanism for the coordination and interaction of individual components within a model (e.g. North and Macal, 2007; Wang and Wsky, 2008; Gonzalez, 2009). Object orientated programming, on the other hand, provides a well-tested framework for organising agents according to their behaviours (North and Macal, 2007). However, scholars explain that agent-based modelling should not be confused with "mobile agents" and "artificial intelligence" that emphasise the development of artefacts that may appear to be human (Thomsen and Thomsen, 1997), Conversely, agent-based modelling emphasises the reproduction of critical features of complex systems using component level rules (North and Macal, 2007). As such, agent-based modelling is said to be an exciting development for researchers wishing to simulate social science insights, permitting scholars to provide a richer perspective of real-world decision making (e.g. Millington et al., 2008; Tabara et al., 2008; Richetin et al., 2010; Smajgl et al., 2009; Bone and Dragicevic, 2010).

There are a number of differences between conventional computer modelling and agent-based modelling. Conventional methods use differential equations and generally assume a well-mixed population with no particular diversity between groups (Jansen, 2005; North and Macal, 2007). Agent-based modelling on the other hand, emphasises the

reproduction of critical features of complex systems, using component level rules. The value of the latter is the opportunity it provides to determine the effect that a particular phenomenon can have on a system as a whole. Regularities can be "grown" to explain the dynamic conditions that led to their existence (Epstein, 1999). This goes beyond conventional computer simulation by generating a rationale for the explanation rather than simply simulating an explanation (North and Macal, 2007). Hence, an agent-based simulation has value for modelling the influence participants have on the confidence building-exercise that characterises risk-based regulation, because it finds solutions that are more robust by capturing the behaviour of a system from the ground up.

An agent-based model is developed by defining behavioural rules – converting knowledge of individual behaviour into an understanding of the overall system – linking individual level actions to negative and positive outcomes (e.g. Epstein, 2006; North and Macal, 2007). 'Behavioural signatures' can be allocated to individual agents (e.g. representing attitudes towards colleagues, co-workers, prior-knowledge, degrees of power and others). Using these rules, an agent can look around its environment, recognise elements and make decisions based on its perception of these elements. In the context of risk-based regulation, a typical decision that an agent may have to make is whether a neighbouring agent, wanting to share knowledge, is trustworthy; for example, to determine whether they wish to grant an application for a waste-management license. After modelling all the agents in such a group decision-making dynamic, the researcher can programme the agents to interact with each other sequentially, in a predetermined order, simultaneously, or in a random order. Calibrating the feedback from running, the model can then illuminate the relative significance of these individual elements to the

overall system, and potentially be used to predict future events and scenarios (North and Macal, 2007).

An agent-based approach can help regulators, environmental planners and policy developers make decisions regarding potential containment options (e.g. Guzy et al., 2008). Behavioural signatures can incorporate spatial and temporal elements to connect all the dots, and helping regulators to understand fully the implications of scientific evidence and/or knowledge, thereby facilitating better decision making than classically inspired optimisation models (Beecham and Engelhard, 2007). In the case of modelling a disease outbreak, an agent world might be set up to reflect a mixed population of known levels of diversity (e.g. regarding the susceptibility of infected and recovered groups). By representing more of the complexity that is known to characterise the real-world phenomena, the modeller can gain a better, more accurate, picture of how a disease outbreak, say, might unfold and what avenues offer the best hope for containment. Hence, agent-based modelling can offer a greater social richness and behavioural realism that is difficult to capture in conventional methods, such as technocratic, one dimensional, risk-management frameworks.

Agent-based modelling has the potential to facilitate governments to explore the influence participants have on risk-based regulation. Governments must manage systems as they grow in complexity. For example, the UK Government currently faces marginal access to regulatory resources because of the increased number of possible outcomes they must consider (e.g. due to EU legislation and regulation). Government departments and agencies have addressed this by trying to make more informed risk-

based decisions, by drawing upon the growing mass of scientific evidence and knowledge. Yet conventional frameworks offer little insight into the influence participant's play. Heroic assumptions often accompany conventional tools for assessing and managing risk (e.g. that employees act according to strict organisational structures or business processes; Paul et al., 1999). This has allowed researchers to gain insight into long run market outcomes, but this offers little insight into the reason why such phenomena occurs (North and Macal, 2007). An agent-based approach, on the other hand, has the capacity to draw upon the growing mass of fine-grained, peer-reviewed, data. Social science literature, for example, explains how people experience different levels of susceptibility to their environmental conditions (e.g. Lauriola and Levin, 2001). Scholars have demonstrated the value agent-based modelling has for incorporating such insights. By taking a more sympathetic approach requiring less assumptions, agent-based modelling offers greater insight into the reasons why future scenarios may occur, making it possible to convert previous experience into visions about the potential future (North and Macal, 2007).

The autonomous nature of an agent-based model alone makes it a good candidate for exploring strategic decision-making. Scholars characterise strategic decision-making as "*the consideration of high levels of uncertainty, potential synergies between different options, long term consequences, and the need of key stakeholders to engage in significant psychological and social negotiation about the strategic decision under consideration*" (Montibeller and Franco, 2009). Agent-based modelling facilitates this through the generation of behavioural signatures' and the growth of regularities, that explain the affect key factors have on alternate outcomes. Hence, agent-based modelling

offers insight in to the day-to-day tactical decisions required to meet a strategic goal. For example, scholars demonstrate how agent-based simulation can facilitate governments to contend with strategic issues, such as:

- river basin land use and waste management (Izquierdo et al., 2003);
- decision support systems for forest ecosystem management (Nute et al., 2004);
- planning for the impact of climate change (Berman et al., 2004);
- modelling the dynamic nature of international greenhouse gas emissions trading (Mizuta and Yamagata, 2001);
- predicting the impact of catastrophic events (Courts et al., 2004);
- the integration of science and policy (McIntosh et al., 2005); and
- the significance of a number of other policy issues (e.g. Brown et al., 2004; Monticino et al., 2007; Perez and Dragicevic, 2009).

These studies emphasise the influence human behaviour has for policy decisions (e.g. Henesey et al., 2006; Mendonca, 2008), clearly demonstrating the advantage of incorporating multiple agents with temporal and spatial elements.

Multi-agent systems can produce powerful results but they can also be difficult to develop. A multi-agent system permits the modeller to exhibit emergent phenomena or generation of unforeseen patterns of spatial aggregation or global behaviour. Essentially, multiple agents are logically interacting entities, motivated by internal states. They use active entities of the original phenomena as actors in the model (Klugl, 2001). However, the absence of a unified formal framework means that modellers often must deal with the complexity of developing an agent-based system rather on their own. Development can therefore be effort consuming and the modeller should consider

whether the advantages justify the additional time and knowledge required. In cases where the development of a multi-agent system cannot be justified the simpler two-agent model may be the solution. An agent-based model that only consists of two agents can offer a modeller the opportunity of obtaining the depth of knowledge required to develop a multi-agent system, should the modeller require a broader knowledge of the phenomena. There are numerous examples in literature that explain the advantages of developing a two-agent model before embarking on the development of a fully-fledged multi-agent model. The following section explains the value of adopting such an approach for modelling the confidence building exercise that is risk-based regulation.

3.7 Agent-based model for simulating the brokering of evidence in risk-based regulation

This subsection discusses the novel development of an agent-based model for risk-based regulation, which accounts for the influence power and personality have on confidence building. In risk-based regulation, confidence is gained through the brokering of scientific evidence. This brokering process is characterised by peer-to-peer (agent-to-agent) communication. Previous sections of this thesis explain that this consists of agents that receive process and pass-on evidence. Agents take it in turns to act as recipients and providers of evidence as it is passed up toward the final decision maker (or makers). Different agents have variable amounts of power to decide and influence the amount of confidence that is attached to submitted evidence. However, the role is essentially the same; agents adopt subordinates' beliefs according to the confidence they place in the evidence and those providing it.

Agent-based techniques have the capacity to go beyond existing decision-support tools by accommodating the influence participants have on the brokering of scientific evidence. Conventional risk-management frameworks set out the logic of information flows and accountabilities, but they fail to accommodate the uncertainty surrounding the influence of personal and organisational features. Others draw upon mathematical theory (such as Multi-attribute Theory, Slovic et al., 1977; French et al., 2005, and Dempster–Shafer's Evidence Theory, Dempster, 1967; Shafer, 1976) to explain how uncertainties, inherent in trade-off decisions, can be accommodated. The latter approach overcomes the limitations of classical probability theory that takes a "closed world" perspective. The advantage of such an approach is its ability to identify uncertainty that has the greatest impact on the overall confidence, potentially informing the deployment of limited resources (Bowden, 2004). However, these methods and frameworks fail to account for the influence personal and organisational features (e.g. personality and power) have on the value judgements participants make regarding sufficiency of submitted evidence and the confidence they attached to it.

Considering the dynamics of the brokering process (as explained earlier in this thesis), it is the belief of the author that the logical framework set by evidence-support logic can be used to form the basis of an agent-based model. Evidence-support logic permits the user to break down a single decision into a number of supporting "child" and "parent" hypothesis until a number of hypotheses with available evidence are identified. When it is used within existing software (e.g. TESLA, developed by risk specialists Quintessa, http://www.quintessa-online.com/TESLA™/), experts come together to assign weights

(ranging from 0 to 1) to reflect how sufficient, dependent and necessary each "child" hypothesis is for answering its corresponding "parent" hypothesis. Then using interval probability theory, beliefs "for" and "against" are propagated from sources of evidence to the central hypothesis and lack of evidence or contradictory belief is reflected as "uncommitted" belief using three-value logic (e.g. Hall et al., 1998). This mimics the way evidence passes through a regulatory framework in risk-based regulation. Evidence supporting risk-based regulation must also undergo the scrutiny of answering a number of queries before it can inform the overall decision. For example, a typical decision might be, does a waste management facility pose an unreasonable risk to its environment? This would be broken down into a number of supporting queries, such as: What risk does it pose to the nearby residence? For a landfill site, this begs the questions; Does it have a clay lining? What is the surrounding geology? Do local residences have cellars? And so on. Once mapped out, this soon represents lines of evidence consisting of consecutive chains of supporting "parent" and "child" query, similar to the chain of hypotheses fould in evidenve-support logic. However, the obvious difference being that each query set out in risk-based regulation represents a participant's role. Participants must make value judgements about how sufficient, dependent and necessary each subordinate query is for answering their query. Decisions may be informed collectively through government guidance, say, but essentially, they are a result of the participant's perception of credibility regarding the evidence and those providing it. If evidence-support logic is to be used as the framework for an agent-based model for risk-based regulation, however, there is a need to demonstrate that each agent can mimic their human counterpart.

There are a number of models that could contribute toward the development of an agent-based model for risk-based regulation. Multi-agent systems, clearly have the capacity to address the influence power structures and communication networks might have on the flow of information within a regulatory framework, or the influence agents attending an expert elicitation panel, say, might have based on the actions of neighbouring agents. For example, scholars demonstrate how multi-agent systems can account for the influence social networks within a society might have on the diffusion of word-of-mouth communication and social value emergence (Kijima and Hirata, 2005). Heterogeneous self-strengthening communication networks have been shown to inhibit leaders passing messages down toward subordinate groups (Liu, 2007). And it has been demonstrated how agents can take action based on the actions of neighbouring agents (e.g. using a multi-agent system, such as FEARLUS, Gotts and Polhill, 2009, to demonstrate the implications that actions of neighbouring agents and aspiration levels had on land mangers decisions). Yet, there is a need to establish whether it is possible to model the peer-to-peer (agent-to-agent) communication, characterising the brokering process, before a fully-fledged multi-agent system can be developed for risk-based regulation.

Development of a two-agent model, representing the dynamic of the brokering process, must attempt to answer whether agents can be equally equipped to cope with negotiations and trade-off decisions in the same way as their human counter parts. Initially this may seem impossible but the logical way in which agents interact is not dissimilar to the logic of the brokering process. Gratch et al. (2008) for example, illustrates how agent-based modelling can be used to show the influence that agents,

focusing on cognitive tasks, had on the perception of portraying positive affect, which in turn promoted cognitive relational processes with the interacting agent. The model reflects how it might be shown that recipients that engage in intelligible conversations with an agent providing evidence (about the sufficiency of evidence say) might have a better chance of imparting knowledge to the providing agent. Hence, possibly explaining how recipients might promote receptivity, and thereby transparency regarding the relative value placed on the submission of different types of evidence, by allowing providers greater access to their internal states.

During the brokering process, recipients and providers come together to negotiate whether or not they agree on the sufficiency of the submitted evidence. Modellers have demonstrated a vast number of personal features that could be accounted for when simulating the outcome of agent-to-agent negotiation. Bonnevay et al. (2005) for example, draws on Cooperative Game Theory to demonstrate the relative influence rational perspectives have on negotiations and the formation of alliances. From this, it is possible to conceive how an agent-based model might be developed to account for the influence personal and organisational features have on the dynamics of a group decision. The model itself was used to explore the influence of rational choice, but conceptually it could be used for the selection of different strategies, justifying why a site inspectors, say, might choose to engage in dialogue over the sufficiency of submitted evidence.

Kawakami et al. (2006) provides another example of how agents might choose to react. The author modelled agents that made decisions based on their desire to balance their

needs with the needs of the interacting agent. The author accounted for the influence participants have on a "proposal-voting process" by permitting agents to make decisions based on their desire to satisfy "physiologically fixed needs" and "social context needs". Similar phenomena can be found in risk-based regulation; for example, when an agent (e.g. a site inspector) chooses to ignore the intentions of another when issuing of a waste management license, say. During the brokering process agents come together to negotiate over the sufficiency of evidence. The outcomes depend on the decisions agents make. Providers must decide what to submit, and recipients must determine the relative sufficiency of the submitted evidence. This requires a balance. Recipients are in the position of wanting to make the right decision and as such want to get as much substantial evidence as they can, to give them confidence that they are not making an error in judgement. However, recipients have to balance this desire with the knowledge that providers do not have unlimited resources and therefore are limited by how much evidence they can submit. Providers, on the other hand, make decisions regarding what evidence to submit. Usually the recipient will instruct them on this. But in real-world decision making the possibility of this happening will depend on the context of the decision (e.g. whether it is appropriate for recipients to do so) and agent receptivity (e.g. how transparent recipients are about what they want, and the likelihood provider will grasp what recipients tell them).

An added advantage of using agents to mimic the brokering process is the natural way they lend themselves toward the sharing of information. The many agents communicate with each other to perform tasks and performance is strongly related to inter-node message-passing. Scholars have demonstrated the value agent-based modelling has for

simulating the effectiveness of trading agents (e.g. Haddawy et al., 2004). For example, scholars have reported on its use for investigating the effectiveness of auctions (e.g. Mizuta and Steiglitz, 2000; Mizuta and Yamagata, 2001; Bohte et al., 2001) buyer coalition schemes (e.g. Yamamoto and Sycara, 2001) and trade brokering (e.g. Alkemade et al., 2003). In models of financial trade, agents are conceived as buyers and sellers of commodity. Incorporating influences, such as motivational feedback, has been instrumental in securing effective price consensus (Mizuta and Steiglitz, 2000). Successful trades are considered those that demonstrate small fluctuations over time. Applying this to risk-based regulation, recipients providing positive feedback might increase the provider's receptivity and thereby understanding of what is expected of them, resulting in fewer fluctuations in the recipient's perception of sufficiency.

The logic set out in an agent-based model of finance and trade lends itself toward modelling the brokering of evidence in risk-based regulation. Scholars that model trading agents within a financial market conceptualise agents as buyers and sellers. Buyers and sellers come together to negotiate the price of a commodity. This commodity has an intrinsic value attached to it for which buyers are willing to pay and sellers are willing to accept. It can be assumed that buyers desire to buy the commodity for a price that is of lesser value than they place in it. Sellers, on the other hand, desire to sell it for more than they value it. Essentially both desire to make a bargain and retain as much money as possible. Success essentially depends on the strategies they employ and their ability to carry these out. However, the commodity may have a greater intrinsic value to either of the agents making successful purchases or sales subjective. Drawing parallels with this process to the brokering of evidence in risk-based

regulation, it is conceivable to view recipients as sellers and providers as buyers of sufficiency.

During the brokering process recipients and providers come together to negotiate over the sufficiency of submitted evidence. In this regard, the commodity that agents barter over is sufficiency. Recipients have it and providers desire it. Again, sufficiency, acting as the commodity, has an intrinsic value attached to it. However, instead of paying for the commodity in pounds and pence (e.g. in money as in the barter of stocks and shares) sufficiency is paid for through the provision of scientific evidence. Again, it can be assumed that providers (as buyers) desire to buy the sufficiency for less than the value they place in it. Recipients (as sellers) on the other hand, wish to sell it for more than they value it. Again, it can be conceived that both want to make a bargain. The provision of evidence comes at a cost to the provider so they want to keep this cost to a minimum. On the other hand, evidence gives the seller confidence, so they want to maximise the amount they get for the measure of sufficiency they attribute toward the providers belief and again success essentially depends on the strategies they employ and their ability to carry them out. Hence, emphasising the need to accounting for the influence personal and organisational features has to account for the confidence gained through the brokering of evidence.

Giving agents personal features (e.g. memory, emotions and personality) gives them a greater measure of intelligence, improving their capacity to mimic human decision-makers. For example, scholars have demonstrated the use of feelings, attitudes and beliefs (Notsu et al., 2006) and other (e.g. Marreiros et al., 2006) have demonstrated

how emotional factors play a role in hypothetical arguments between participants in a multi-agent system. Marreiros et al. (2006) reported that agents in a good mood were more risk averse than agents in a bad mood, who wanted to make agreements quickly in order to achieve a good mood. On the other hand, scholars such as Izquierdo et al. (2007) have demonstrated how memory can give an agent the capacity to learn from those around them, and thereby avoid unsatisfactory experiences. The influence this may conceivably have on the brokering of evidence is demonstrated by Xu and Griffiths (2010). Building on Bartletts' (1932) theoretical explanation of "serial reproduction", Xu and Griffiths reported that the memory (and the biases retained within it) resulted in disturbances to the transmission of information. By combining these mechanisms agents with emotions and memory have the potential to show how different events and scenarios may impact the brokering of evidence. However, simply accounting for the influence of emotions and memory is insufficient for explaining how an agent might make decisions in the same way as participants engage in the brokering of evidence.

Personality can rationalise the link between perceptions, emotions and behaviour. Psychologists consider personality to be a coherent pattern of different kinds of behaviours and interactions within their environment (Page, 1983; Pervin, 1987). As such, attributing agents with personality is considered one of the most fundamental ways of replicating human decision-making; by making agents more human-like and flexible by attributing them with thoughts, desires, and emotions, typical of a real world decision maker (Rizzo et al., 1997).

Once incorporated within an agent-based model, scholars explain that personality "traits" can be varied to map out the influence they have on different behaviour. Nassiri-Mofakham et al. (2009) for example, gave agents personality by adopting a heuristic semi-dynamic approach toward bargaining. In so doing, the author was able to demonstrate the effectiveness of enhancing the realism of rational bargaining behaviour by using more human-like agents. Personality-based agents were more flexibility, permitting the author to investigate the effectiveness of future negotiations by focusing on the preservation and resolution of conflict. Moreover, agents with dynamic personality gave the agent the capacity to update their personality knowledge (e.g. according to changes in personality facets Ghasem-Aghaee and Ören, 2003; 2007). Scholars illustrate how this can be done by matching the importance of facets to the situation. For example, permitting by determine agent's openness to experience, by matching the availability of facets the cognitive complexity required to successfully engage in problem solving. To achieve this, Ghasem-Aghaee and Ören (2003; 2007) permitted the dominant facet (e.g. fantasy, aesthetics, feelings, ideas or values) to determine what value of openness to experience to give the agent. This allows changes in decision context to affect the modelled cognitive complexity of the individual and their ability to function.

Agent-based models that incorporate measures of personality have the potential of offering greater insight into the influence participants have on the brokering of evidence. For example, scholars have illustrated how personality can be used to represent agents functioning in the face of uncertain information (Neuberg and Bertels, 2003; Wojcik, 2004) and the influence relative levels of risk aversion may have on the

decisions they make (Neuberg and Bertels, 2003). However, the most inspirational use of personality for the development of an agent-based model for risk-based regulation is the study by Dimuro et al. (2006) who demonstrated the value of incorporating personality to investigate the regulation of social exchange. The model had a supervisor agent whose role it was to pass messages between personality-based agents to maintain a social equilibrium. The model was not intended to represent group decision making per se but its logic clearly lends towards modelling the brokering process. The supervisor agent, for example, is representative of evidence being passed between recipients and providers. Personality gave the agent the capacity to regulate the supervisor's access to their internal state, hence, demonstrating how personality could be used to reflect the impact of simulating transparent and opaque agents.

Transparency is an important aspect that must be accounted for. Site inspectors, for example, play a different role compared with a project manager of a Post-Closure Safety Case for nuclear waste disposal. A site inspector's role is to be very prescriptive as they instruct the operator on what evidence to submit. On the other hand, a project manager's role is not to instruct but to advise. They advise the operator on what type of evidence might be expected but essentially the onus lies with the operator to decide what to submit. An agent playing the role of a project manger therefore would have a rationale for being less transparent about the value they place on different types of evidence; compared to the site inspector who should be completely transparent.

This subsection has discussed the novel development of an agent-based model for risk-based regulation that accounts for the influence power and personality have on

confidence building. Existing decision-support tools fail to account for the fact that confidence building is carried out through the brokering of scientific evidence. However, a number of scholars have demonstrated the ability to incorporate social-science theory within an agent-based model. In particular, scholars explain some of the advantages of allowing agents to have relative amounts of power to decide, and how it is possible to incorporate aspects of transparency by giving an agent personality. Of particular interest to this thesis is the framework set out within evidence-support logic. By mapping out lines of evidence as consecutive chains of supporting "parent" and "child" hypothesis, it provides a suitable structure on which to model risk-based regulation. Each hypothesis can represent a query characterising a participant's role in the group decision, conceived to either be in a position of wanting to sell or buy units of sufficiency, dependency and necessity. Following on from the logic of financial trade, recipients can be conceived as sellers and providers as buyers of sufficiency. Then weights can be added to reflect the relative influence power and personality has on confidence building in risk-based regulation.

3.8 Chapter summary and conclusions

This chapter has provided a critical review of the literature relating to this research project and a presentation of identified gaps in knowledge. It is asserted that agent-based modelling has the capacity to fill these gaps in knowledge that exist regarding the influence that social science aspects of decision making (specifically power and personality) have on the brokering of scientific evidence in risk-based regulation.

Section 3.3 explained how Government departments and agencies, in the UK, have the remit of carrying out environmental decision making. However, environmental decision making is fraught with uncertainty, primarily because of the absence of evidence and/or the presence of contradictory evidence. In an attempt to account for this, Government departments and agencies have published risk-management frameworks that set out a summary of the key actors involved. However, they pay little homage to the fact that decisions-made are acted upon by people, and as such, fail to account for the influence value judgments have in determining whether a risk is perceived to exist, and to what level.

Risk characterisation (a statement on the significance of a risk and its attending uncertainties) has been described in Section 3.4 as the most fundamental aspect of risk management, allowing the development of feasible options for abating risk. To facilitate the division of expertise and responsibilities, government have often assumed they can handle uncertainties in the relevant science. Lines of evidence informing environmental decisions, however, rarely point in the same direction (i.e. are rarely universally supportive of a particular query), come in various strengths (of evidence), and thus require synthesis so an overall weight of evidence can be applied to the characterisation (significance and confidence) of the risk. Hence, the process in which evidence is brokered is also inherently uncertain due to information gaps, the existence of competing theories and the presence of manifold uncertainty.

Section 3.5 sets out those that have already reported on how individuals make decisions under uncertainty, through both theoretical models and extensive empirical testing. In

this regard, power is explained to be an individual's ability to control ones environment and the behaviour of those within it. Personality, on the other hand, is explained to be one of the most powerful measures of interpersonal processes. Substantial literature exists on the dynamics of power and personality. This section explains how French and Raven's (1959) five forms of power, and the Big Five measure of personality (Costa and McCrae, 1992) relates to this brokering process. Moreover, how their combined influence can be captured in distinct *if... then...* behavioural signatures, to explain the influence they have on agent receptivity/confidence regarding the sufficiency of the submitted evidence.

Section 3.6 and 3.7 explain how agent-based modelling has the capacity to address the influence participants have on the brokering of evidence in risk-based regulation. A number of examples are presented to illustrate this and explain how an agent-based model is developed by defining behavioural rules – converting knowledge of individual behaviour into an understanding of the overall system – linking individual level actions to negative and positive outcomes. This is suggested to have the potential to explain how and why participants might make decisions. The autonomous nature of an agent-based model alone makes it a good candidate for exploring power structure and personality influences. It is explained that even a simple two-agent model can provide valuable insight that would not otherwise be obtainable through static analysis. An added advantage is the natural way agents lend themselves toward the sharing of information. Also, the capacity they have to mimic human behaviour by expressing a measure of intelligence after being endowed with personable features (e.g. memory, emotions and personality). Therefore, for this work, a simple two-agent based model

was selected. The development of this model is shown in Chapter 7 whilst the validation and application of the model to case studies is given in chapter 8. Development of such a model would be a novel for risk-based regulation, and a step toward a fully-fledged multi-agent system.

This page is intentionally blank

Chapter 4

RESEARCH METHODOLOGY

4.1 Chapter Structure

This chapter sets out the potential method options that could have been used to address the research question set out in chapter 2 along with the selection of the most appropriate method.

4.2 Description of options for methodological choice

There are two fundamental methods of reasoning: deductive and inductive research. The extent to which research adheres toward either of these two methods of reasoning will define the research approach. Generally, inductive reasoning is the most socially based, focusing on the human factor and making sense of the variability and unreliability that characterises these systems. Deductive research, on the other hand, moves from the general to the more specific, and is often referred to as the traditional way of reasoning when it comes to scientific research.

The approach adopted in this thesis was neither purely deductive nor purely inductive. It is inductive in so far that it attempts to draw broad generalisations from specific observations (made by the author and others) about the manner in which participants

influence risk-based regulation, specifically through their involvement in the brokering of scientific evidence. The research is also deductive in its approach (moving from the specific to the general), as it tries to draw conclusions from the developed agent-based simulation model.

Looking beyond the research approach, there were a number of potential strategies available to address the research question stated in Chapter 2 (e.g. Creswell, 1994). Each research strategy has a distinct way of collecting and analysing empirical evidence, each with its own advantage. For the purposes of this thesis, the research question had to address "how" and "why" participants affect the brokering of evidence in risk-based regulation. Research strategies, such as case studies, surveys, experiments and historical analysis, are well suited for addressing the "how" and "why" research question (Yin, 1984). However, the goal was to investigate phenomena with a real-life context, where the boundaries between phenomena and context are not evident, requiring multiple sources of evidence to be drawn upon. Therefore, the research strategy selected was the 'case study', as through these decisions can be considered and analysed for why they were taken, how they were implemented, and with what result (Schramm, 1971). The alternative strategies would have struggled to achieve this. Experiments divorce phenomena from context; historical analysis, which although it deals with the entanglement of phenomena and context, is limited to dealing with non-contemporary events; and surveys, able to address the interplay between phenomena and context, are limited in the breadth of context they are able to investigate to the number of variables and questions they can practically incorporate (Yin, 1984). Hence, the most appropriate research strategy for this thesis was the 'case study' because it

permitted the investigation of the influence participants have on risk-based regulation by focusing specifically on the dynamics of the brokering of scientific evidence in risk-based regulation.

This body of research considers three types of case study: the live, the constructed and the available type of case study. The latter proving most suitable due to its provision of instant access to information regarding decision protocol and decision outcomes. This information was readily available within peer reviewed journal articles and government guidance, specifically concerning risk-based regulation. The live and constructed types of case study did promise a greater insight into the role participants played in actual decisions. However, there was little likelihood of gaining access to participants because of the contentious nature associated with many regulatory decisions. Moreover, the period associated with the real-world regulatory decisions meant that the live and constructed type case study could only provide a snapshot in time of the influence that participants have on decision outcomes. In addition to this, extensive knowledge already exists to tell of how participants and groups of individuals influence decision outcomes, specifically concerning the role that power structures and personalities play.

Having selected a research strategy the next step was to choose a method of data collection. Scholars generally categorise research methods as either being qualitative or quantitative in nature (e.g. Lee, 1992; Bryman, 1988; Berg, 1995). Selection of the research method required a determination as to whether applying it to the target population was possible. Sample size can be an important factor in establishing a measure of reliability, validity and credibility (DePaulo, 2000). However, given the

contentious nature of each of the selected case studies it was not possible to sit-in on the actual regulatory decisions and, as a result, each case study had to be investigated (modelled) offline. To overcome this, and to ensure a measure of feasibility, the initial phase of the research placed an emphasis on in-depth interviews. Such interviews are useful when the people involved in a phenomenon have insights that are not otherwise available (Wainwright, 1997). In line with this, a greater emphasis was placed on the quality of insights rather than on the number of respondents sharing it.

Agent-based simulation was the chosen method for modelling risk-based regulation. There are a number of alternatives that could have been used, but as it will be explained, these are limited in scope. An alternative to using agent-based modelling and simulation was the option to use a decision-support method or technique. A vast number of decision analysis tools exist to cope with the complexities that characterise decisions under risk and uncertainty. Conventional methods, however, lack the transparency and explanatory power that agent-based modelling can offer. In particular, the influence social science insights have on the confidence-building exercise that characterises risk-based regulation. Issues that generally affect risk-based decisions include; clarity of problem definition, gathering of evidence, structuring of arguments, brokering of evidence, peer review and defensible decisions.

The value of decision analysis lies in its ability to identify areas of conflict between stakeholders. The conventional approach has been to provide a more complete understanding of the values held by stakeholders. To this end, scholars have been applying methods such as Multi-attribute Analysis, Analytical Hierarchical Process

(AHP) and a number of outranking methods (e.g. ELECTRA and PROMTHEE) and statistical/probabilistic methods (e.g. Bayesian Belief Networks). Over the years, these methods have helped decision makers cope with the type of complexities and nuances that characterise risk-based regulation. Decision analysis uses mathematical theory to address the complexities of decision making under risk and uncertainty. At their core, they provide a structured way of balancing trade-offs and exploring policy options. The inherent complexity of environmental decision-making dictates that problems can be decomposed into sub-problems to show how they individually affect the overall problem. However, the complexity characterising risk-based regulation that requires different solutions for different problems has given these a limited applicability.

Government risk-based regulation is inherently characterised by a high conflict potential. The sheer number of issues that must be accounted for means that evidence is lacking and levels of uncertainty are high. Decision-support tools used in economics (e.g. cost benefit analysis (CBA) and cost effectiveness analysis (CEA)) have a history of facilitating government to explore the implications (cost and benefit) of alternative actions. This facilitates decisions under uncertainty (Farmani et al., 2009). Cost benefit analysis, for example, has been used extensively to model the impact socio-economic costs, say, have on options appraisal and the distribution of limited resources. However, critics claim that CBA, like many other economic models of human behaviour, struggle to translate insights gained from quantitative analysis into meaningful expressions of confidence without neglecting qualitative aspects of supporting evidence, in the final analyses.

Multi Criteria Analysis (MCA) is said to overcome the shortcomings of economic decision-support tools by permitting the use of qualitative criteria in the analyses. For complex decisions under uncertainty, MCA can incorporate multiple (conflicting) criteria and preferences about present and future impacts. AHP, for example, is among the most widely used and fastest growing MCA techniques, currently being used in a number of disciplines, including environment and resource planning and management (Bello-Dambatta et al., 2009). AHP permits the user to mimic the structure of real-world risk-based decisions, providing a framework of information flows and accountabilities. By breaking down problems into smaller ones, it has the potential to facilitate communication of issues, making them more transparent and understandable to lay people. Representing the structure of decisions provides greater clarity over trade-offs between different objectives and interests. However, as they stand, such methods can imbue the user with a false sense of security by presenting an oversimplified perspective of alternatives. Elghali (2002) for example explains how the unequivocal or impartial approach of life-cycle analysis (LCA) can result in credibility results and problems in public policy debates. Repeatability is also an issue, even with experienced practitioners. Moreover, the reliance that MCA techniques place on gaining access to high quality data about information and uncertainties poses a problem for their use within risk-based regulation, characterised by high ambiguity and uncertainty.

Uncertainty that pertains to human behaviour is a major contributor and an essential element of successful environmental decision-making, however, conventional methods fail to account for its influence. Scholars have tried to address the issue through the adoption of hybrid decision-support tools, for example,

by integrating Bayesian Belief Networks (BNN) and Evolutionary Multi-objective Optimisation (EMO). These maximise on the strengths and have the potential to overcome limitations inherent in conventional hierarchical models. Using design variables (e.g. perception of vulnerability, removal of point source pollution and non-point pesticide application), they have the potential to evaluate and weigh the pros and cons of each action in order to help obtain fairer more balanced perspective of the decision (Farmani et al., 2009). Of significance to risk-based regulation is the potential they have to account for the impact that inputs from multiple decision makers can have on decision outcomes, potentially resulting in a large number of high quality non-dominated policy options (Farmani et al., 2009).

Non-dominated policy options characterise those options that are not dominated by a single person or group within the policy process, offering a well balanced perspective of the views and opinions of those involved. In the past, information and power imbalances has meant that those positioned with superior knowledge and resources were able to dominate the framing of issues and shapping of conclusions (e.g. such as in the BSE crisis; Rothstien, 2003). Non-dominated policy options acknowledge that risk-based regulation is not value free (Munton, 2003) and that it must draw upon a sources of knowledge outside the conventional regulatory structure to reduce the chance of policy error (e.g. Majone, 1989; Funtowitz and Ravertz, 1996). Conventional approaches, however, struggle to achieve this because they fail to acknowledge that in practice institutional factors shape the decision-making process.

Hybrid approaches have the potential to facilitate the bringing together, and combining of insights, in a way that could help regulators and policy developers make better decisions that are more informed. However, they are inherently limited to deterministically modelling the way knowledge informs decisions made. Agent-based modelling and simulation, on the other hand provides a greater versatility, allowing component level rules to be combined to generate macro-level complexity. In the context of risk-based regulation, this can be used to explore the complexities and nuances (e.g. power structure and personality influences) that characterise the brokering of evidence. It has the capacity to take a retrospective view of risk-based regulation and use this insight to generate potential futures that can facilitate regulators, policy developers and environmental planners to better understand the implications of their decisions. The alternatives to agent-based modelling, mentioned here, would not have been able to deliver this.

Agent-based modelling and simulation enabled the empirical modelling of the influence that individual personalities and power structures have on confidence building, overcoming what otherwise would have been an extensive timeframe to investigate these issues in real-time. By simulating qualitative insights, abstracted from interviews and contained in published literature, agent-based modelling helped to draw broader conclusions regarding the influence participants may have had on the brokering of evidence in risk-based regulation.

In summary, the research methodology presented in this chapter is a product of much exploration, carried out in the three distinct phases. Phase 1 is addressed in Chapter 5

and considers the dynamics of the brokering process and selection of case studies that represent this process across risk-based regulation, generally. Phase 2 is addressed in Chapter 6 and addresses the brokering process within each case study and the development of the framework that could facilitate this. Finally, Phase 3 is addressed in Chapter 7 and 8. Chapter 7 sets out the development of an agent-based model for brokering evidence generally, and Chapter 8 demonstrates this within the context of each case study.

The remainder of this section explains that each phase consists of two parts. The former part of Phase 1 explains how in-depth unstructured interviews were carried out to explore the dynamic that characterises the brokering of evidence in risk-based regulation. The latter part of Phase 1 consisted of rationally selecting the three case studies (nuclear waste disposal, the disposal of avian influenza infected animal carcases and dietary salt intake), and mapping out the logical flow of the brokering process in each case study. The former part of Phase 2 explains how knowledge gained in Phase 1 was used to carry out in-depth semi-structured interviews to understand better the dynamics characterising the brokering of evidence and knowledge. The latter part of Phase 2 explains how knowledge of the dynamic way evidence is brokered in risk-based regulation and known power and personality influences, informed the development of a research framework. The former part of Phase 3 explains how the research framework was used to develop an agent-based model that could incorporate known influences of power structure and personality together with lessons learnt regarding the dynamics of the brokering process in risk-based regulation. The latter part of Phase 3 explains how permitting components of the decision-making environment and the agents to be varied

facilitates simulation of real-world two-person interactions that characterise the regulator/applicant relationship in the context of the three selected case studies selected in the latter part of Phase 1.

4.3 Phase 1

The objective of Phase 1 was to explore the dynamics that characterised the brokering of evidence and select three real-world case studies that represented the breadth of conditions under which scientific evidence was brokered in risk-based regulation.

4.3.1 In-depth unstructure interviews to explore the dynamics of the brokering of evidence in risk-based regulation

A series of five in-depth face-to-face unstructured interviews were carried out with current and former Environment Agency (EA) regulators. The purpose of these interviews was to 'get a feel' for the issues that characterise the brokering of evidence in risk-based regulation. A number of authors have reported on the value of carrying out in-depth unstructured interviews (e.g. Burgess, 1984; Minichiello et al., 1990; Berry, 1999; Broom, 2005; Dawson; 2007). Unstructured interviews provided means of obtaining insight into the dynamics of the brokering process otherwise inaccessible through conventional methods.

During the in-depth unstructured interviews, the interviewer (Gareth Davies) only had a brief topic guide; i.e. "*What was the participant personal role in group risk-based*

regulatory decision-making; and what role did the brokering of scientific evidence and knowledge have to play?" This allowed considerable freedom for the interviewee to explore different topics within the context of the brokering process. In line with others, these interviews took the form of conversations permitting access to historical information (Berry, 1999; Bryman, 2001; Dawson, 2007), regarding participant's involvement in the brokering of scientific evidence and knowledge. The interviewer had the task of establishing rapport; building trust to gain access to intimate detail regarding respondent's rationale for participants receiving, processing and passing on (or not) evidence and knowledge. To facilitate this, the interviewer made a conscious effort to keep their input to a minimum whilst remaining alert. This ensured the brokering process was characterised by the respondent's own perspective. In-depth interviews thus provided a way of entering into the respondent's world; exploring their understandings of the brokering process and gaining insight into how scientific evidence and knowledge was valued, constructed and negotiated within the context of group risk-based regulation.

The interviewer gained access to each of the respondent via mutual contacts, with some respondents acting as gatekeepers to other. Each interview followed a common agenda. The interviewer began by introducing the research topic; explaining the purpose for the interview and the expected duration. Next, the interviewee was assured confidentiality of personal details before being asked for permission to use a Dictaphone to record the interview. Then, by asking respondents to explain their role in group risk-based regulatory decisions and the brokering process, the interviewer probed respondents (at opportune times) to expand on the significance that scientific evidence and knowledge

had to play in decision outcomes. The interviewer wrote-up field notes after each interview to capture insights that could inform the development of the semi-structured interview schedule and then transcribed (verbatim) a two-hour interview to facilitate in the development of the initial agent-based model.

4.3.2 Selection of three real-world case studies characterising the breadth of conditions under which scientific evidence is brokered in risk-based regulation

The latter part of Phase 1 consisted of selecting three real-world case studies that represented the breadth of conditions in which scientific evidence is brokered in risk-based regulation. To this end, a systematic review of available literature was carried out to understand the type of issues that Government departments and agencies must contend with, including:

- novelty;
- scientific uncertainty;
- bureaucracy;
- environmental planning;
- policy development;
- technical/regulation;
- public dread;
- flexibility of the decision framework;
- emergency response; and
- geographical dispersion.

Three case studies were required to represent the breadth of conditions under which scientific evidence is brokered in risk-based regulation. To this end, this list of attributes, common to all of the issues investigated, provided the author with a means of selecting three case studies that could represent a broad perspective of risk-based regulation (Table 1).

Table 1: Case studies considered as potential candidates

	Novelty	Scientific uncertainty	Bureaucracy	Environmental planning	Policy development	Tactical / regulation	Flexibility of the decision	Public dread	Emergency response	Geographically disperse
1. Risk associated with the disposal of avian influenza infected animal carcasses	X			X					X	
2. Risk associated with the dietary salt intake					X		X			X
3. Risk associated with nuclear waste disposal		X	X			X		X		
4. Risk associated with an outbreak of blue-tongue disease	X	X				X			X	
5. Risk associated with seasonal flooding				X					X	X
6. Risk associated with the disposal of hazardous waste to landfill		X	X			X				

Available regulatory frameworks were then compared against the common attributes and used to identify three case studies that could represent the brokering of evidence generally in risk-based regulation. The three case studies selected included the regulatory review of a post-closure safety case for nuclear waste disposal (a regulatory decision), the disposal of avian influenza infected animal carcasses (an environmental planning decision) and the proposal to reduce levels of dietary salt intake (a policy development decision). The three case studies were also selected based on the breadth of motivational factors known to characterise group decision-making (e.g. Pfeffer and Sutton, 1999; Hanf, 2006; Scholten et al., 2007; Figure 8), which included the following:

- known and hidden hierarchical structures;
- variability between individuals at the same level in the decision hierarchy;
- dominant factors such as individual interests and pay-offs (e.g. political aspects, such as the implications of getting it right); and
- transparent and opaque (hidden and public) features.

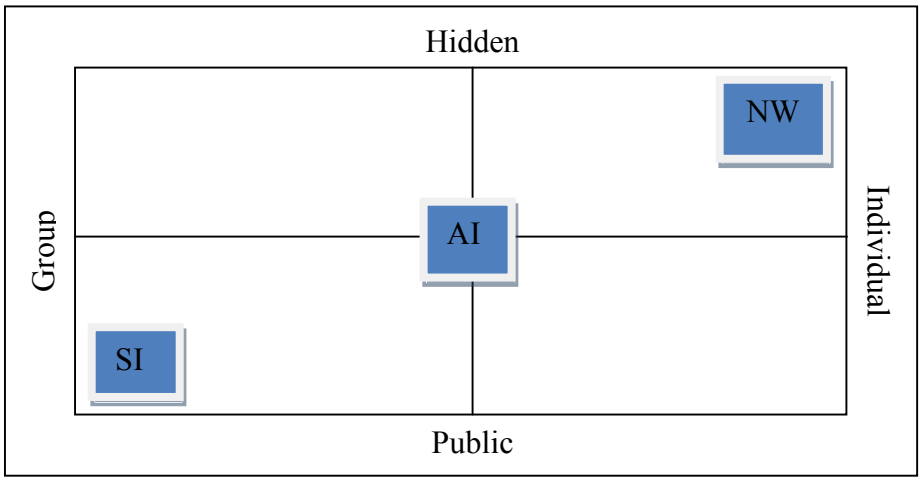


Figure 8: Matrix used to assess the identified case studies.

Having identified three case studies, the next task was to map out the brokering process within each decision. Then, a systematic review of the available literature was carried out, explaining the directional flow of evidence and accountabilities that characterised each framework. Figure 9 illustrates the process followed to carry out a review of regulatory frameworks published by Government departments and agencies in the UK.

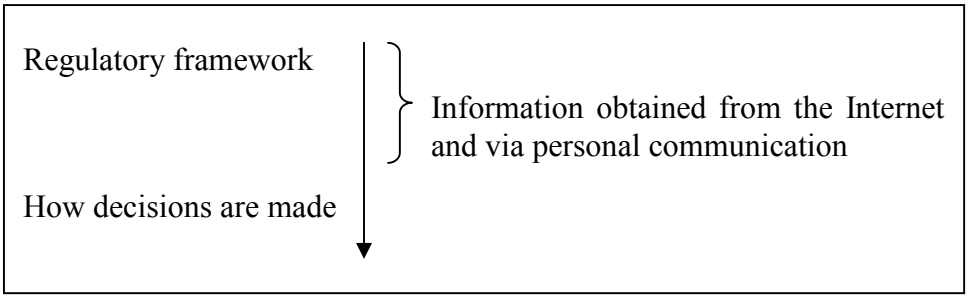


Figure 9: Illustrating the process used to carry out a review of the different regulatory frameworks published by Government departments and agencies in the UK.

Because information regarding the brokering of evidence within governmental regulatory framework is generally spread across a number of different documents, the information was mapped out using "Mind-Manger Pro". These maps were too large to be practically used within the planned semi-structured interviews, therefore the general flow of information and relative accountabilities were mapped out using a methodology set out by OXERA (2000). Figure 10 illustrates the methodology set out by OXERA (2000). It explains how the logical flow characterising the brokering of evidence and the different actor's involved can be mapped-out.

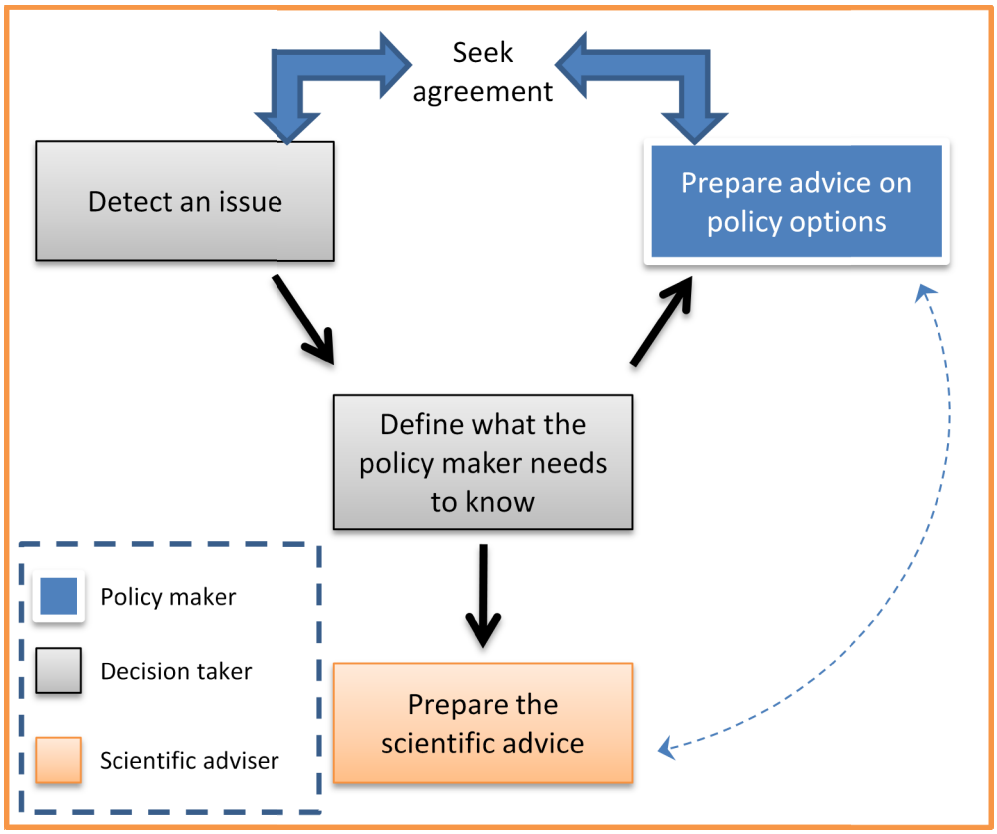


Figure 10: Model of a process for acquiring and securing scientific data (Adapted from OXERA (2000).

OXERA (2000) developed this methodology specifically for investigating the advisory process in policymaking. This thesis applies the same logic to policy development, environmental planning and regulatory decisions. The methodology helped clarify functions and contributions, avoiding ambiguity and uncertainty regarding the brokering process. Then during the in-depth semi-structured interviews, these maps provided a useful means of validating the interviewer's understanding of the process with experts.

4.4 Phase 2

The individual objectives of Phase 2 were to carry out semi-structured interviews and develop a research framework in order to model the brokering of evidence in risk-based regulation. Interviews permitted the dynamics of the brokering of evidence to be mapped-out in each case study. Development of the research framework, on the other hand, enabled the illustration of the logic of the brokering process that characterised each case study.

4.4.1 In-depth semi-structured interviews to describe the dynamics brokering of evidence in the three selected case studies

To fulfil the first objective; semi-structured interviews were carried out with an expert from each case study. The purpose was to validate the interviewer's understanding regarding the directional flow of evidence and the relative accountability participants had in each case study.

Interviews were used because the goal was to gain an understanding of the respondent's social reality regarding the brokering of evidence. The semi-structured interview is the most common type of interview used in qualitative social research (Dawson, 2007). Numerous scholars have reported on the value of this approach (e.g. Patton, 1990; Dawson, 2007; Fontana and Frey, 2005). For this thesis, they provided the means to repeat the same questions in each case study, whist allowing respondents the flexibility to respond in a variety of ways and raise issues pertinent to the research. Phase 1 of this

research project, was used to develop an understanding of the issues that the respondent might cover, but it was essential that this knowledge was validated. In addition, it was necessary to gain a connected account of the brokering process that could explain how people got involved and had an influence. Semi-structured interviews represented the best means of gaining access to this type of information.

The design of an interview schedule (see Appendix) facilitated the consistency necessary for a comparative study. This ensured that the questions were asked in the same way for each decision. Interviews were guided but flexible to allow clarification of important connections between elements of narratives. The interview schedule had three distinct stages, moving from the general to the specific and back again (Figure 11). The primary objective was to validate who got involved; the role these people played; and the context in which they had to make decisions. Inspiration for the design came primarily from Powell (1999) who carried out a study into the use of science at the EPA, and numerous other scholars that offered advice on how to design and carry out an in-depth semi-structured interview (e.g. Wisker, 2001; Yin, 1984; Fontana and Frey, 2005).

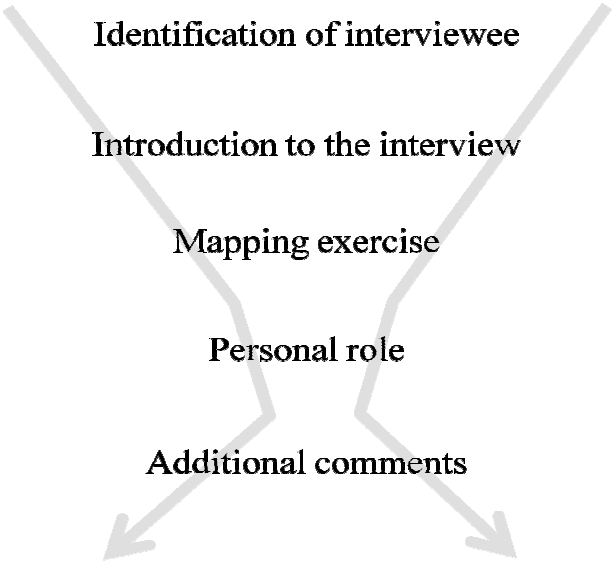


Figure 11: Interview Schedule, where the change in the horizontal distance between the directional arrows illustrates how the focus of decisions moved from the general, to the specific and back again.

Before the interview began, the interviewer introduced the research topic and asked respondent's permission to use a Dictaphone to record the interview. During the 'mapping exercise', the respondents were presented with the map of the brokering process and asked whether they agreed with its logic. This encouraged respondent to talk generally about the brokering process and the role scientific evidence and knowledge played. The respondent was then directed to elaborate on the flow of information within this brokering process by asking a series of questions regarding the external process, points of entry, internal process and the actual decision made.

The next stage aimed to delve deeper into the respondent's knowledge of the brokering process. This stage, entitled 'personal role', required respondents to break the decision

down into three or more phases using a time line. In each of the identified phases, the respondent was asked a series of questions characterising: their involvement; the evidence and knowledge brokered; and the actions participants had to carry out. Drawing on the content of the unstructured interviews and descriptions of the advisory process contained in Powell (1999) and OXERA (2000), the respondent was required to rate the extent to which evidence and knowledge could be characterised as being qualitative, quantitative, political, social, technical and costly. Finally, in the latter stage of the interview schedule the respondent was asked a general question regarding the role they perceived risk-based approaches to play in past, current and future regulatory decision-making. The aim was to give respondents the opportunity to talk more generally in the hope that this would spark further discussion about the importance of risk-based regulation and the brokering of evidence and knowledge.

These interviews were limited in the sense that it was possible to gain access to only one respondent within each case study. This reflected the contentious nature of the research topic and general unavailability of the target population. The interviewer was given access to willing respondents via a research colleague who had personal contacts in the relevant organisations. Before each interview, respondents were sent formal notification, explaining the purpose of the interview, reasons why they were chosen, the expected duration of the interview and how information would be recorded and kept confidential. This information was re-explained to respondents who consented (via email and telephone) and the time and place to carry out the interview was agreed. In each case, the interviewer met with the respondent at their place of work, which for those respondents who worked from home, was their place of residence. After each

interview, the interviewer transcribed (verbatim) the audio files, read the transcripts in depth and abstracted content relating to the brokering process (i.e. the receiving, processing and passing on (or not) of scientific evidence).

4.4.2 Development of a research framework capable of capturing the logic of the brokering of evidence in risk-based regulation

The latter part of Phase 2 required the development of a research framework that had the capacity to capture the logic of the brokering of evidence in risk-based regulation. This was achieved by identifying an existing framework capable of representing how a number of different lines of evidence inform policy development, environmental planning and regulatory decisions. This framework was expanded upon by incorporating influences of power structure and personality, allowing the exploration of the relative influence participants have in determining the sufficiency of scientific evidence supporting a group decision.

To develop a research framework, the logic set out within TESLA, software developed by risk specialists Quintessa (http://www.quintessa-online.com/TESLA/) was used as source material. TESLA uses evidence-support logic (ESL), based on interval probability theory (IPT), to represents how different lines of evidence inform a group decision. It starts by breaking down a group decision into a number of supporting 'parent' and 'child' hypotheses. Next it applies weights to reflect how sufficient and necessary each 'child' hypothesis is for answering its 'parent' hypothesis; and how dependent two or more 'child' hypothesis are for answering a corresponding 'parent'

hypothesis. Then by using IPT, ESL propagates up degrees of belief 'for' and 'against' and represents uncommitted belief as missing and contradictory evidence. Building on this logic, the author integrated known power structure and personality influences, to develop a research framework capable of mapping out the logical way that scientific evidence supports decisions within risk-based regulation.

Known power structure and personality influences were incorporated within the identified framework by developing a model that could calculate a weight (between 0 and 1), reflecting the recipient-agent's receptivity toward a providing-agent's belief. Known influences were arranged in a hierarchical fashion, relative to the influence they had on the receiving, processing and consultation stage. Then, an overall receptivity value was obtained by assigned weights (ranging between zero and one) to each factor to reflect the 'relative' influence each had on agent receptivity within each stage. Low, medium or high weights, assigned to each bottom level factor within each stage was propagated up the hierarchy. An overall weight reflecting agent receptivity within the brokering process was then derived by taking the average weight across all relevant stages. Agent receptivity within the receiving stage and the processing stage was always considered relevant, but agent receptivity within the consultation stage was only considered relevant if the recipient agent had motivation and legitimate power to engage in consultation. If the former was true then the overall receptivity was the average of the total receptivity calculated for each stage, but if the latter was true, it was only the average of the total receptivity calculated for the receiving and processing stage.

Agent receptivity (ranging between 0 and 1) was incorporated within the research framework by multiplying it together with the relevant weight reflecting sufficiency of the provider's belief. The receptivity and sufficiency weight each ranged between zero and one, representing zero and one hundred percent respectively. Multiplication was used to combine these two weights. In turn, anything other than one hundred percent sufficiency would result in less than one hundred percent of the provider's belief 'for' and 'against' a query being taken onboard by the recipient agent. Hence, permitting the framework to incorporate power structure and personality influences. However, this framework did not show the influence dialogue between agents would have on recipient receptivity and thereby sufficiency. This is addressed in Chapter 7 through the development of an agent-based simulation model.

4.5 Phase 3

Phase 3 adressess the third, fourth and fifth research objective by developing an agent-based model that could simulate the influence power and personality had on the brokering of evidence (and thereby confidence building) in risk-based regulation. The model is described in Chapter 7 and investigates the possibility of developing an agent-based simulation model for representing interacting decision makers. Chapter 8 demonstrates how stable decisions regarding the sufficiency of evidence are susceptible to changes in system parameters and the extent to which the automated decision making system is able to reach the same decisions as those described in the three real-world case studies.

The influence participants had on the brokering of scientific evidence was modelled within a two-agent simulation model.

The model was programmed within Microsoft Excel Visual Basic Editor, using Visual Basic Application (VBA) code. VBA is easier to use than other more sophisticated programming languages (e.g. C++), thus allowing rapid development of the agent-based model.

The two-agent model evolved from the logic set out with the developed research framework. This initial attempt was limited and could not account for the dynamics nature of the consultation stage. This version of the model was not dynamic and therefore oversimplified the brokering process. The next version did account for the dynamic nature that characterises recipients and providers of evidence that come together to negotiate over the sufficiency of submitted evidence. This was achieved by developing a number of object models in VBA and determining the one that best represented the brokering process.

The general logic was to use a numbers of "Loops" within VBA to update agents' personal information relating to:

- propensity to trust,
- trustworthiness,
- positive and negative prior knowledge, and thereby their willingness to approve,
- motivation to process evidence systematically and carefully,
- motivation to share knowledge with the interacting agent,

- referent power.

Each of these were updated according to the logic abstracted from the interviews and peer reviewed literature.

Chapter 7, described how the logic set out in the developed research framework was used to design an agent-based simulation model. The objective was to develop a model that was capable of representing actors as 'nodes', coded to illustrate the relative impact interacting agents had on decision outcomes (e.g. by representing how motivations, functions, characters and protocols influence decision outcomes). Figure 12 summarises how this objective was met. Information regarding the position of individuals within a decision hierarchy and the directional flow of evidence between participants shown in the figure was abstracted from Government guidance and confirmed by carrying out in-depth semi-structured interviews with experts. This, together with existing knowledge regarding the influence personality and power has on motivations, functions, characters and protocols, was coded within Excel Visual Basic Editor resulting in an agent-based model. The developed model was capable of exploring the role that power and personality has on group risk-based decisions.

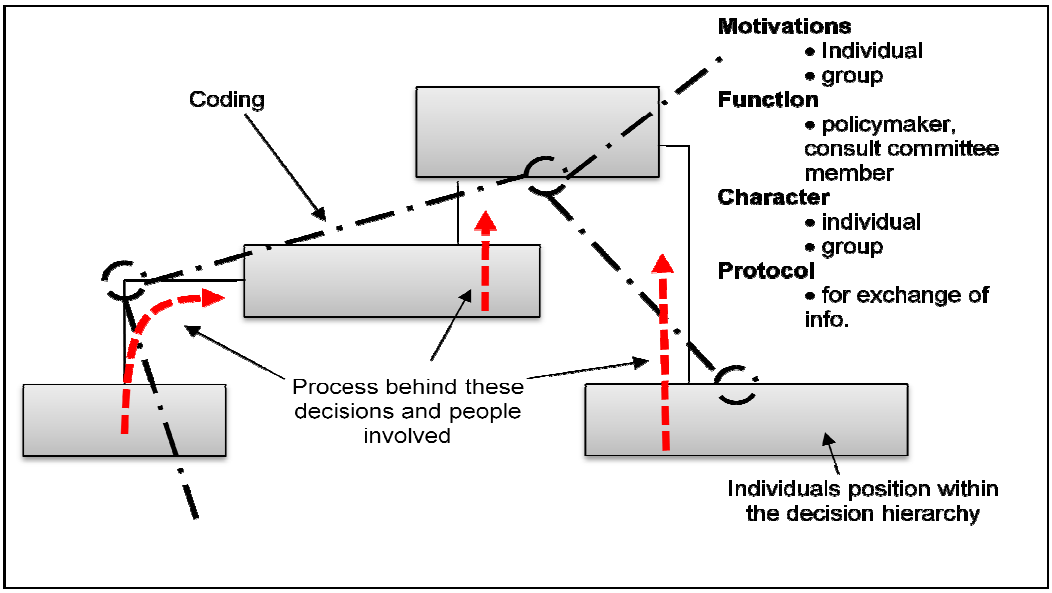


Figure 12: General processes by which the author investigated the brokering of evidence in risk-based regulation. Representing how formal roles (▭) set out in Government guidance and the directional flow of information (⇢) were coded within Microsoft Excel to create a two-agent simulation model.

The developed agent-based model is not a typical agent-based model. Generally, agent-based models include multiple agents that focus on how complex dynamics and outcomes can rely on the network of interactions among the agents. In this regard, the developed agent model is quite simple compared to more conventional multi-agent systems. The model only contained two agents. However, despite its simplicity Chapter 8 demonstrates that it is able to produce interesting results regarding the relationship that can exist between a regulator and an applicant, say. The actual range of real-world two-person interactions that the model is intended to illuminate is outlined in Chapter 7.

The development of the agent-based model permitted representation of dialogue between agents could affect their variable influence in determining the sufficiency of scientific evidence and knowledge. This was achieved by defining agents that receive and agents that pass-on scientific evidence and knowledge, as sellers and buyers respectively. Recipients had units of sufficiency to sell and providers had access to scientific evidence and knowledge to exchange for these units of sufficiency. However, the extent to which providers were successful depended on how much confidence each submission of evidence gave recipients. This depended on how the evidence and knowledge was characterised by different types of information (social, political, technical, qualitative and quantitative aspects). If the relative weight assigned to each type of information matched a recipient's pre-existing idea of how much weight should be assigned to each type of information, the evidence and knowledge was assumed to be successful in imbuing the recipient with confidence.

Published findings (e.g. Powell, 1999; OXERA, 2000) and insights contained within the in-depth unstructured and semi-structured interviews were used to determine information type and individual relative weight in each case study. In the developed agent-based model, the recipient's receptivity weight was used to determine whether the provider knows or will have to guess how the recipient values the different types of information.

4.5.1 Simulating the effect power structure and personality have on the brokering of evidence in risk-based regulation

The second objective of Phase 3, was addressed by abstracting scenarios (from the in-depth semi-structured interviews) influencing recipient's receptivity in the receiving, processing and consultation stage. Secondly, each scenario was ranked as either having a low, medium or high influence on recipient's receptivity and given a score to reflect the magnitude of its effect. Then, during each interaction, the agent-based model randomly selected a scenario known to influence recipient's receptivity, relevant to each stage of the brokering process, and incorporated this influence into the overall recipient's receptivity weight. Hence, the model provided a means of exploring a decision's stability as well as its sensitivity to changes in system parameters. Moreover, this permitted the assessment of the quality of the decisions and exploration of what interactions could lead to specific decision outcomes.

Chapter 8 presents the initial sensitivity analyses carried out on the two-agent model. It is presented as the first step in a process toward gaining insights into which probabilities require high accuracy and which do not. Kala and Kala (2009) explain that there are two types of sensitivity analyses; the deterministic and the stochastic sensitivity analyses. Deterministic (otherwise referred to "design sensitivity") entails carrying out a parametric study by investigating a number of "What-if" scenarios. Organising these as a sequences of calculations with gradual variation of input parameters in each calculation makes it possible to discover the influence each parameter has on the measured response. Stochastic sensitivity analyses, on the other hand, offer a more in-

depth quantified insight into the influence of parameters. Stochastic methods go beyond deterministic approaches providing insights into differential sensitivity values for estimating the influence parameters have on measured outputs (Irving, 1992). The process is similar to the deterministic approach, with changes to parameters being used to investigate how their effect manifests itself on the output variable. However, the stochastic methods require a number of assumptions to be made based on the modellers knowledge of parameter distributions. The level of detailed knowledge regarding parameter distributions was not available at the time of analysis. Therefore, deterministic sensitivity analysis of the influence model parameters had on agent's receptivity and confidence was carried out in this thesis. Hence, whilst the sensitivity analysis presented in Chapter 8 lacks sophistication it does help to focus future elicitation effort to be placed on more critical probabilities of agent's receptivity and confidence building.

The link between interactions and specific decision outcomes was considered by looking at a number of "what if" scenarios. These scenarios were characterised by narratives taken from in-depth semi-structured interviews. Outputs from the model were then triangulated with insights abstracted from the in-depth semi-structured interviews, and peer-reviewed literature (Figure 13) to provide a measure of rigour. Rigour is generally understood as an essential component for carrying out quality research (e.g. Morse et al., 2002; Golafshani, 2003). The triangulation, attempted to ensure results could be generalised to a wider population than that of the sample group.

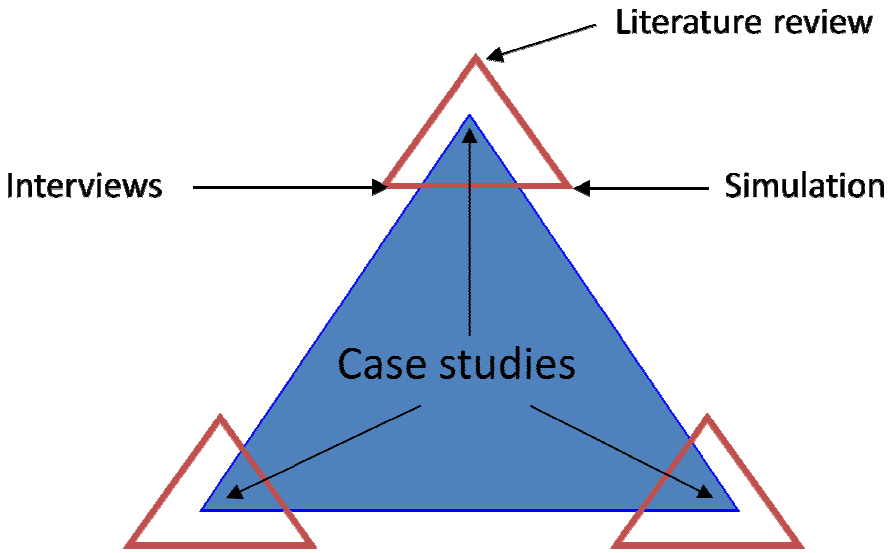


Figure 13: Methodology used to triangulate insights. Where, each angle of the large triangle represents one case study and each angle of the smaller triangles represents how insights regarding the brokering of evidence were gathered.

4.6 Chapter summary and conclusions

This chapter has provided an overview of the selected research methodology. A justification for the selected methodology is given, followed by an explanation of the method employed to carry out each of the three phases of this research project; the exploratory phase (Phase 1), the descriptive phase (Phase 2) and the model development and proof of concept phase (Phase 3).

This page is intentionally blank

Chapter 5

EXPLORATORY STAGE

5.1. Chapter structure

This chapter presents the results from the first stage of the investigation; insights gained by carrying out in-depth unstructured interviews and the process of selecting three real-world decisions characterising risk-based regulation. The objective of the exploratory stage was to model government decision-making by examining real-world case studies. To this end, this chapter has carried out in-depth unstructured interviews to explore the dynamics that characterise the brokering of evidence. Thereafter, it has selected three real-world case studies that provide a broad perspective of risk-based regulation and the conditions under which scientific evidence is brokered.

5.2. In-depth unstructured interviews carried out to explore the dynamics of the brokering of evidence in risk-based regulation

In-depth unstructured interviews (otherwise referred to as informal conversational interviews e.g. Patton, 1987; Fontana and Frey, 2005; Minichello et al., 1990), were carried out with experienced regulators. The primary purpose of carrying out these interviews was to gain some insights that would serve as the foundation for in-depth semi structured interviews (presented in Chapter 6).

These interviews were successful in providing a better understanding of the type of contextual issues that characterise the brokering process. The advantage of adopting an unstructured approach was the freedom that it gave the respondents to explore various scenarios. Moreover, scholars generally agree in the need to undergo training before carrying out in-depth interviews (e.g. Burgess, 1984; Dawson; 2007). In this sense, these interviews acted as a training ground on which to prepare for carrying out the semi-structured interviews.

In total 5 regulators were interviewed. All of these respondents were either former or current employees of the Environment Agency and had first-hand experience of brokering evidence in risk-based regulation. These included one licensing officer and three environment officers. Figure 14 provides a connected account of the process in which interviews were carried out and analysed. This illustrates the process from contacting the respondents to processing and analysing the interview transcripts. As explained in Chapter 4 respondents acted as gate keepers to other respondents. During each interview, respondents talked through their experiences of making (and informing) risk-based regulatory decisions and explained the role evidence and knowledge had to play. These interviews were recorded and transcribed. Then transcripts were read and reread to search for common themes (and items) that characterised the process by which evidence was brokered in real-world government risk-based decisions.

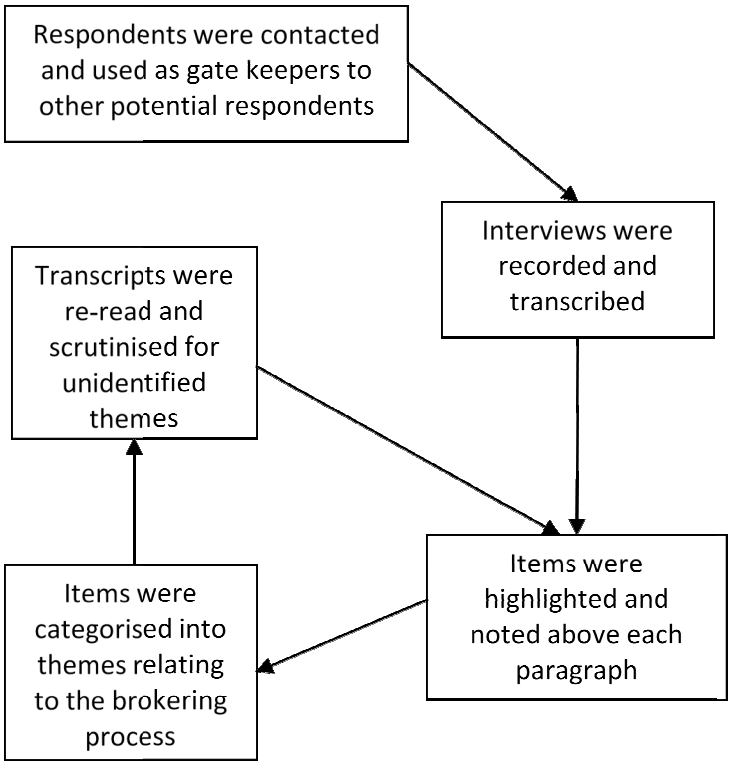


Figure 14: *Connected account of how respondents were identified, interviews were recorded and how transcripts were processed and analysed.*

Each interview contributed towards building an understanding of the dynamic process that characterised the brokering of evidence. From the interviews conducted, the following observations were made:

- The participants engaged in the brokering of evidence in risk-based regulation played one of two roles; they either played the role of a recipient or the role of a provider of evidence. Each person, however, would at some point play both roles during the brokering process; and
- The agents (people) that got involved, passed through three distinct stages: the receiving, processing and passing-on stage.

These three processes are shown in Figure 15. The two prominent directional arrows in the centre show the cross over of information between the receiving stage to the processing stage and from the processing stage to the passing-on stage. However, the dashed arrow at the bottom of the figure illustrates that this is not a deterministic process. There is often a feedback whereby information coming from the receiving stage may increase the resistance permitting the transfer of evidence to the passing-on stage. It was explained during the interviews that this often occurred when the evidence entering the receiving stage was highly contentious, making the decisions whether to issue the waste management license, say, a political one.

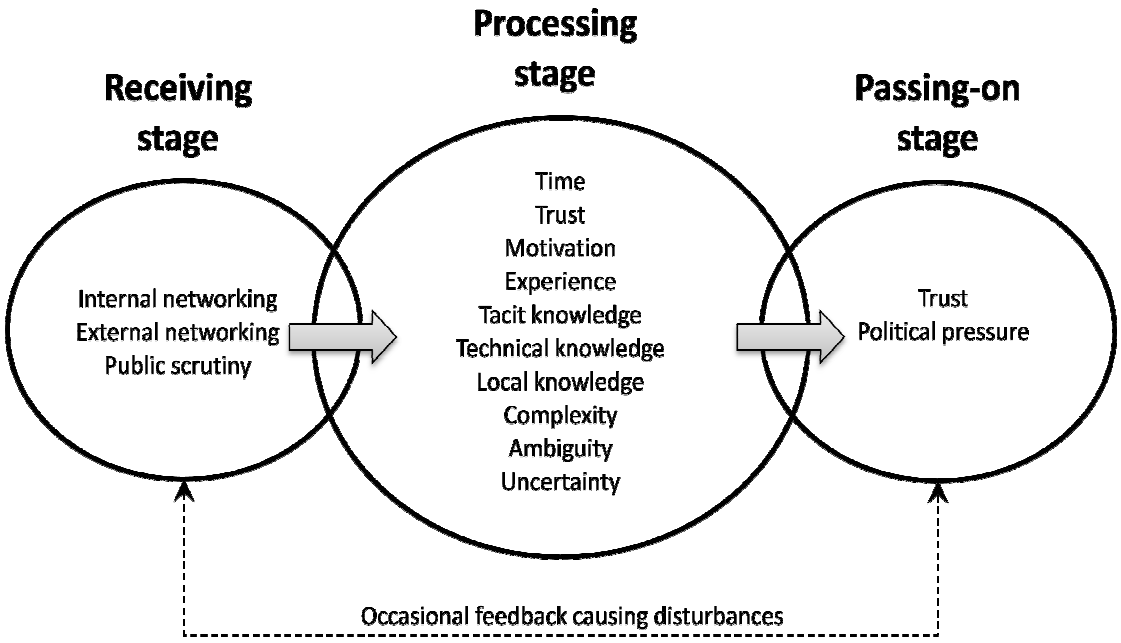


Figure 15: *Items categorised under the three main themes of the brokering process in risk-based regulation; the receiving stage, the processing stage and the passing-on stage.*

In each of the circles illustrated in Figure 15 there are a number of items that appeared to characterise each theme (the receiving, processing and passing-on of evidence). This is not an exhaustive list (see Appendix), but it does refer to those that were mentioned specifically with regards to the brokering of evidence.

The receiving stage essentially determined what information was made available to the recipient. Factors that contextualised the receiving stage were related to the recipient's access to internal and external networks. During the receiving stage, evidence became available to the recipient at a rate that was dependent on two aspects; the recipient's tenacity to seek out evidence and the number of voluntary submissions made by the applicant and/or any number of onlookers, such as statutory consultees. The former was said to be influenced by the recipient's personal information. Willingness, for example, was described as being based on the recipient's positive and negative prior knowledge. This was suggested to influence whether the recipient was likely to accept what the provider was telling them, and whether they would decide to seek out new sources of evidence. On the other hand, voluntary submissions were suggested to be a consequence of the context of the decision being made. For example, decisions that were considered to affect a greater number of stakeholder groups were believed to be the type of decisions that would attract a greater number of voluntary submissions of evidence.

The evidence the recipient reviewed was also explained to be linked to recipient's knowledge (e.g. whether they knew what was required and where to find it). This was illustrated by a respondent explaining the importance that both informal and formal lines of communication played in decision outcomes. For example, in the context of

obtaining scientific advice, one respondent explained that this was greatly helped by knowing who to talk to:

> "*I know who to ring in policy and process it would actually give me an answer on the day rather than having to go through a more formalized route…"*

Passing through the formal route was said to be a long drawn out process that could restrict them from gaining vital knowledge in time to make their value judgements. Referring to the formal route of gaining advice from the policy team was said to be inaccessible because of the time it took to get a response,

> "*essentially you write your query that then goes to another person who then sends it to head office and then about twelve years later you get your answer"*

Hence, it also was the character of the regulator that determined whether the lines of evidence were likely to be available to them in the receiving stage. Given that the regulatory waste licensing officers only get 28 days to consult on a licence, it was not difficult to understand that relying on formal lines of communication severely restricted the regulators' access to important information regarding the type of evidence they would receive. Using this same example, the respondent explained that it was their experience and knowledge of who to talk to that determine whether they would have gained access to particular types of evidence.

> "*over time you get to learn who is likely to answer their phone or if you drop them an e-mail who might come back because sometimes you cannot reach someone"*

In the processing stage, recipients had the task of assessing how sufficient the submitted evidence was for answering a pertinent question (e.g. whether a waste management license should be issued). At the top of the list characterising, this stage (seen in Figure 15) is "time". Time in the context of the brokering process is referred to as a recipient's authority (otherwise known as a legitimate power). A recipient was said to be restricted to making their decision regarding the sufficiency of submitted evidence within this given period. However, in the context of issuing a waste management license, the licensing officers acting as recipients did have the discretionary power to decide to accept the submitted evidence before this time period has elapsed, if they felt that sufficient evidence had been submitted. As such, decisions made within this stage were said to be made based on the recipients' perception of how credible and reliable the evidence and those providing it were.

During the processing stage the recipients (e.g. regulators) process the different submissions of evidence based on the information he/she receives, e.g. regarding how credible or reliable the evidence is. This could be influenced by the regulator's view of the operator in terms of credibility as well as the scientific evidence provided. The outcome determines what information the regulator would pass on.

In this regard, respondents generally referred to three types of operator; the good, the bad and the ugly, which they trusted successively less. The environment health officers were more explicit about this, probably because of the nature of their role to inspect compare to the licensing officer's role to assess. However, all the respondents referred

to a number of different types of operator that could be generally categorised under these three headings.

Respondents explained that sometimes they "just knew" that an operator would knowingly pollute the environment. This was explained as the ugly type of operator. They were said to be fully aware of what they ought to do, had the capacity to do it, but were just unwilling to comply. Believing this was the case, regulators mentioned how they would constantly ask the operator to submit evidence that could refute the regulator's concerns, but they reported that they constantly met with resistance from the operator. For example, one environment health officer mentioned that a particular site was known to be polluting but nothing could be done to stop them until they obtained the necessary evidence. The full extent of the regulator's coercive power was exercised but in the case mentioned the regulator explained that the required evidence probably would not appear unless the operator was taken to court.

The bad type of operator did not knowingly pollute the environment but lacked the skill base (and sometimes understanding) to comply with some of the regulators requests for evidence. These were "bad" in the sense that the regulator did not have the supporting evidence that the regulator required to not fine them, say, but they were not considered to "ugly" in the sense that they would not knowingly pollute the environment and try to hide it by refusing to submit evidence. In the processing of this type of evidence, respondents explained that they would give the operator as much time as possible. Often the "bad" operators were referred to as the "friendly farmers" who had an excellent track record but lacked the skill base required to prepare a management plan. The good

type of operator, on the other hand, was those that were in contrast to the ugly type of operator. These were described as knowing what to submit, had the resources to do so and were openly motivated to do so.

The passing-on stage involved transferring the processed information to other personnel (such as a boss or a team leader) who were responsible for further decision making. The passing-on stage consisted of answering whether the regulator had sufficient evidence to support their claim. If it was a political decision and the supporting evidence lacked legitimacy, it was said that the result would likely be that the regulator would not be permitted to pass-on the evidence. This may result in the regulator returning back to the processing or even the receiving stage to review what is being passed on, for example, requiring the regulator to engage in dialogue with the operators' consultant.

An important element that interlinked the processing and passing-on stage was trust held between participants. This was said to have a substantial influence on participants' ability to process and pass-on evidence. For example, on one occasion it was explained how the ability to pass-on evidence was facilitated by the regulator's boss having trust in their ability to make good judgements.

> *"...your boss has to sign it because he actually has the power to sign the form... but [I did] all the work and to be honest I think normally your boss doesn't normally go through the documents in a huge amount of detail partly again because we talked about the site lots"*

Another example of how a contextual issue influenced the passing-on of evidence was political pressure. For example, in the context of issuing a license that received public attention one respondent explained:

> *"it ... appeared in the paper 4 weeks in a row on the front page ....the area manager the environment manager got involved everyone started to get a lot more concerned which they always do when it goes public"*

By going public, it meant that the respondent engaged in more consultation with the provider of information. In addition, it meant that the respondent increased their demand for particular types of information. The respondent explained:

> *"awful lot more people all got involved than…. probably a lot hotter on odour than I would normally…. I did get them to do a lot more work… did have a five to six revisions of their area management plan which we really shouldn't have done"*

In summary, the in-depth unstructured interviews served as a useful means of preparing the author for carrying out the in-depth semi-structured interviews. They demonstrated the complexity that characterised the brokering of evidence. This demonstrated that non-scientific contextual issues were also important and must be considered to understand the dynamic behaviour of participants engaged in the brokering of evidence.

One outcome from these interviews was the understanding that between the primary source of evidence and the final decision maker (the "top" and "bottom" agent), at any given time during the brokering process there must exist an agent that receives and an agent that provides evidence. Also, each of these agents must play both roles at some

point and must pass through three stages; the receiving, processing and passing-on stage. The themes and items presented in this section are heuristic codes that broadly represent the dynamic of the brokering process.

Essentially, throughout the process, there are interactions between two individuals participating in the brokering process – a recipient and a provider. This interaction is seen between the operator and the regulator, the regulator and his peers/team leader and (possibly) between regulators and consultants with the possibility of roles reversing. The individuals play various roles in this process, similar to the work described by OXERA (2000). The recipient receives information and depending on his/her role places a value on the information received before passing it on with this value attached to it. The next section introduces the three case studies being investigated in this thesis.

5.3. Selection of three real-world case studies that characterise risk-based regulation

The three case studies were selected to provide a relatively broad perspective of the conditions under which scientific evidence was brokered. These included the regulatory review of a post-closure safety case for nuclear waste disposal, the disposal of avian influenza infected animal carcasses, and the recommendation for the reduction of dietary salt intake. Each issue drew on a complex evidence base to inform a regulatory, policy development and environmental planning decision, respectively.

Figure 16 provides a connected account of the process followed to review available regulatory frameworks. Common attributes were identified and three decisions

representing a relatively broad perspective of risk-based regulation and the brokering of scientific evidence were selected. The decision making process was mapped out with Mind Manager Pro and distilled into three flow charts depict the directional flow of evidence and relative roles different actors played, using a methodology developed by OXERA (2000).

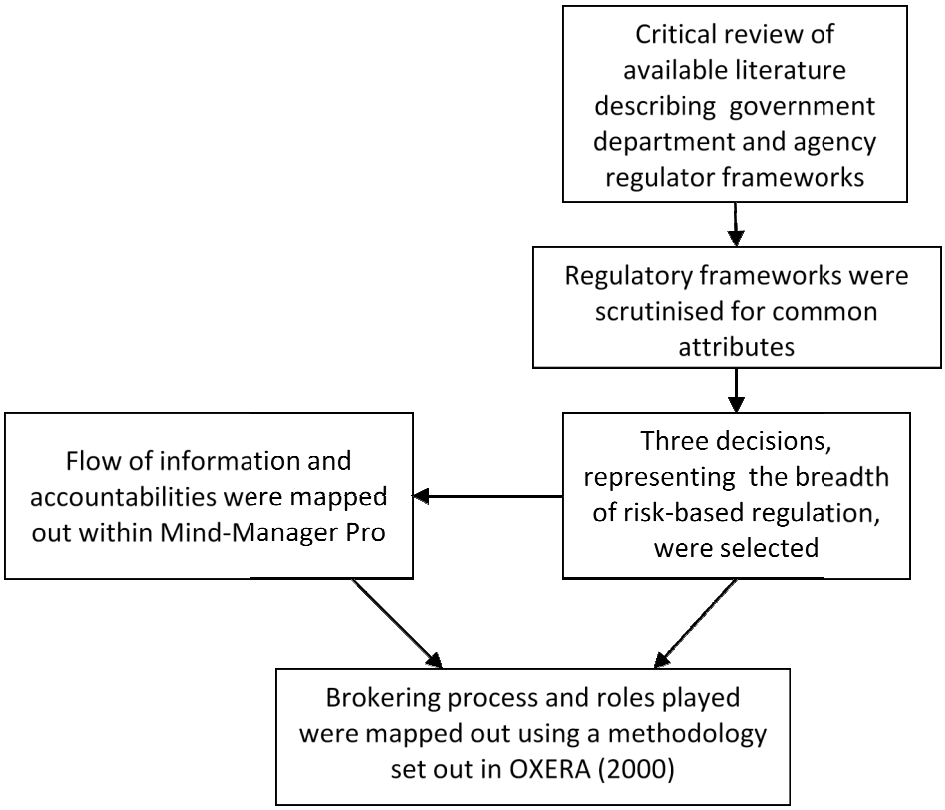


Figure 16: Connected account of how three case studies representing the breadth of risk-based regulation were selected.

Each case study was characterised by relative levels of scientific uncertainty, public dread, accountability, and inflexibility of the regulatory framework in which decisions have to be made (Figure 17). The former two characteristics necessitate the latter two. That is, Government managed the increased level of public dread and scientific

uncertainty associated with each risk by requiring a greater level of accountability, and a rigid regulatory framework.

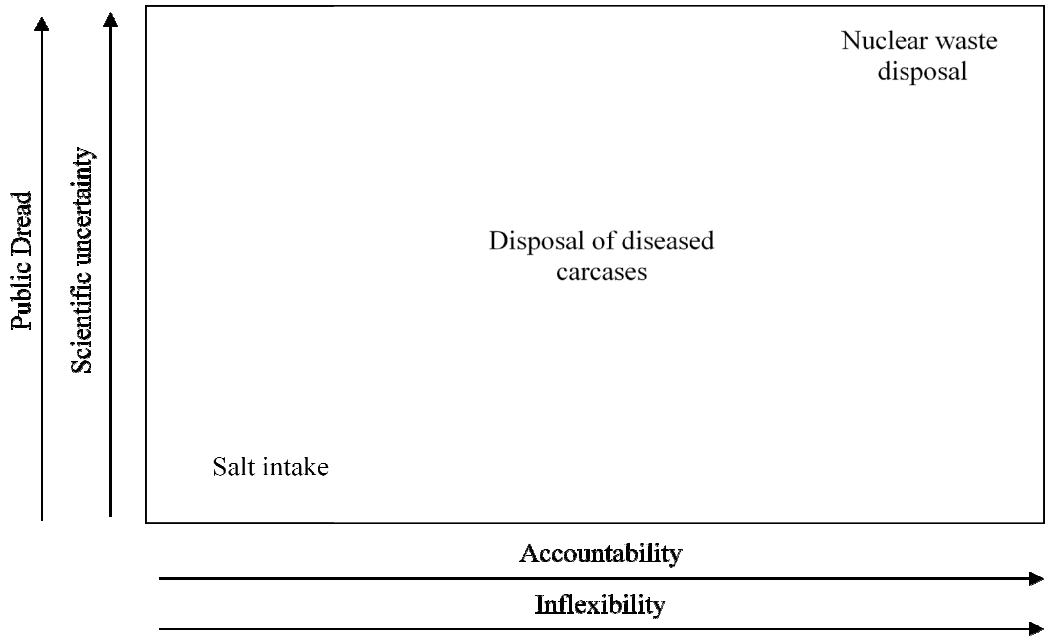


Figure 17: illustrates how the three selected case studies (dietary salt intake, disposal of avian influenza animal carcasses, and nuclear waste disposal) range in the extent to which they are characterised by relative levels of public dread, scientific uncertainty, accountability and inflexibility of the regulatory frameworks from which decisions are made.

The first case study (the risk associated with dietary salt intake) was well known characterised by a relatively low level of public dread and scientific uncertainty. The risk was not high on the public agenda and the Food Standard Agency (FSA) did not have the legal power to coerce food manufactures, for example, to comply to exacting standards. As such, the risk was being managed in a relatively flexible risk management framework.

The Food Standards Agency (FSA) was responsible for carrying out the salt intake decision. Set up in 2000 the FSA is an independent Government Department without a Minister. Its purpose is to protect the interests of consumers in relation to food and drink issues. Their primary concern is making sure consumers can buy safe food and that they can make informed choices about the food their buying and its nutritional content. High concentrations of dietary salt have been reported to result in a significant increase in high blood pressure, which was linked to coronary heart disease (Korhonen et al., 1999). Reducing salt intake was reported to reduce average blood pressure levels in a clinical dietary control, in both sexes (Sacks et al., 2001). In the UK, the Food Standards Agency (FSA), an enforcement authority in their own right, set voluntary targets for reducing the average salt intake for adults to 6g per day, based on recommendations made by the Scientific Advisory Committee on Nutrition (SACN). Because these targets were voluntary their primarily aim was to encourage retailers and manufactures to reduce the concentration of salt in their food products. As an incentive, the FSA published league tables based on attempts made by organisations to meet this target. The FSA also ran major public health campaigns, with other organisations, aimed at reducing the amount of salt in 'social cooking'. They also recruited and trained local peer facilitators to work with minority ethnic groups, and make the public more aware, generally, of the large amounts of salt that was added to their food.

The second case study, the risk associated with coordinating the disposal of diseased animal carcases, was characterised by a relatively medium level of scientific uncertainty. The risk that the regulator had to contend with was better known than that associated with nuclear waste disposal, but not as well known as the one associated with

dietary salt intake. As such, the risk associated with the disposal of avian influenza infected animal carcasses still warranted a greater level of accountability than that of dietary salt intake. This case study was therefore characterised by a relatively medium level of scientific uncertainty.

In the UK, the Department for Environment, Food and Rural Affairs (Defra) is responsible for coordinating disposal of infected animal carcasses. This represented a decision that was characterised by emergency response and where the timeframe was short. This required Defra to have a good working knowledge of all the potential pathways that could lead to exposure. This required participants to maintain good working relationships so that expert advice could be sought quickly. A certain amount of trust is essential because everything needs to fall into place quickly. Therefore, much of the risk assessment work was carried out ahead of time. Evidence and knowledge was then disseminated within Government guidance to operational staff in the form of a generic contingency plan. In the event of a disease outbreak, Defra used this information in collaboration with expert advice from a number of different parties (e.g. health departments and their agencies, veterinary officials, environment agencies, emergency planners and other professional partners) to inform their decisions on the most appropriate suite of disposal options.

Finally, the review associated with the post-closure safety case for nuclear waste disposal is characterised by a relatively high level of scientific uncertainty. This required that the Environment Agency assess and manage risk within a relatively rigid

and inflexible regulatory framework, reflecting the need to establish accountability and address a relatively high level of public dread.

The Environment Agency (EA) is responsible for the authorisation of radioactive waste disposal in England and Wales (under the Radioactive Substances Act 1993, as amended). British Nuclear Fuels plc (BNFL) was the operator authorised to carry out the disposal of solid low-level radioactive waste located near the village of Drigg on the Cumbrian coast, in northwest England (Duerden et al., 2003; El-Ghonemy et al., 2005). In accordance with public policy, repository operators underwent a periodic review of their status by preparing a post-closure safety case for the regulator. The goal was that the post-closure safety case would contain sufficient evidence to give the Agency confidence that the operator was managing the risks associated with the disposal of nuclear waste appropriately. In preparation of this safety-case, the operator was required to make good use of scientific evidence and knowledge. Yet, the assessment and management of future risks, given the longevity of radioactivity, posed a considerable intellectual challenge in terms of the availability and reliability of scientific evidence and knowledge. This placed a substantive burden of proof on the operator to evaluate future risks up to 100,000 years forward in time. To accommodate this, the Environment Agency required the operator to draw upon reasoned argument, future scenarios, and structured approaches to the 'evolution' of the repository over time. This was encouraged alongside the use of quantitative field and modelled data in support of the operator's post-closure safety case. After the formal submission of the safety-case and consultation with all relevant parties was complete, the inspecting officer had to make a recommendation for authorisation, or re-authorisation for existing facilities, to

the Secretary of State, based on the evidence and knowledge provided. Moreover, this case study took approximately four years to play out characterised by a relatively high level of consultation thereby providing the author with the opportunity to investigate the impact dialogue had on decision outcomes.

Having selected three case studies that characterise the scope of decisions made in risk-based regulation, the next task was to map out the directional flow of evidence and roles different actors had in brokering the evidence. To do this, the methodology set out by OXERA (2000) was used. The methodology was intended to be used by government departments to facilitate mapping out their policy process. These served as a useful discussion point in the semi-structured interviews (presented in the proceeding chapter). The logic set out in Figures 18, 19, & 20, regarding the directional flow of evidence and the relative roles played by decision-takers, policy-makers, scientific advisers, and stakeholder representatives were mapped out using information available on the internet and validated within the semi-structured interviews in Chapter 6.

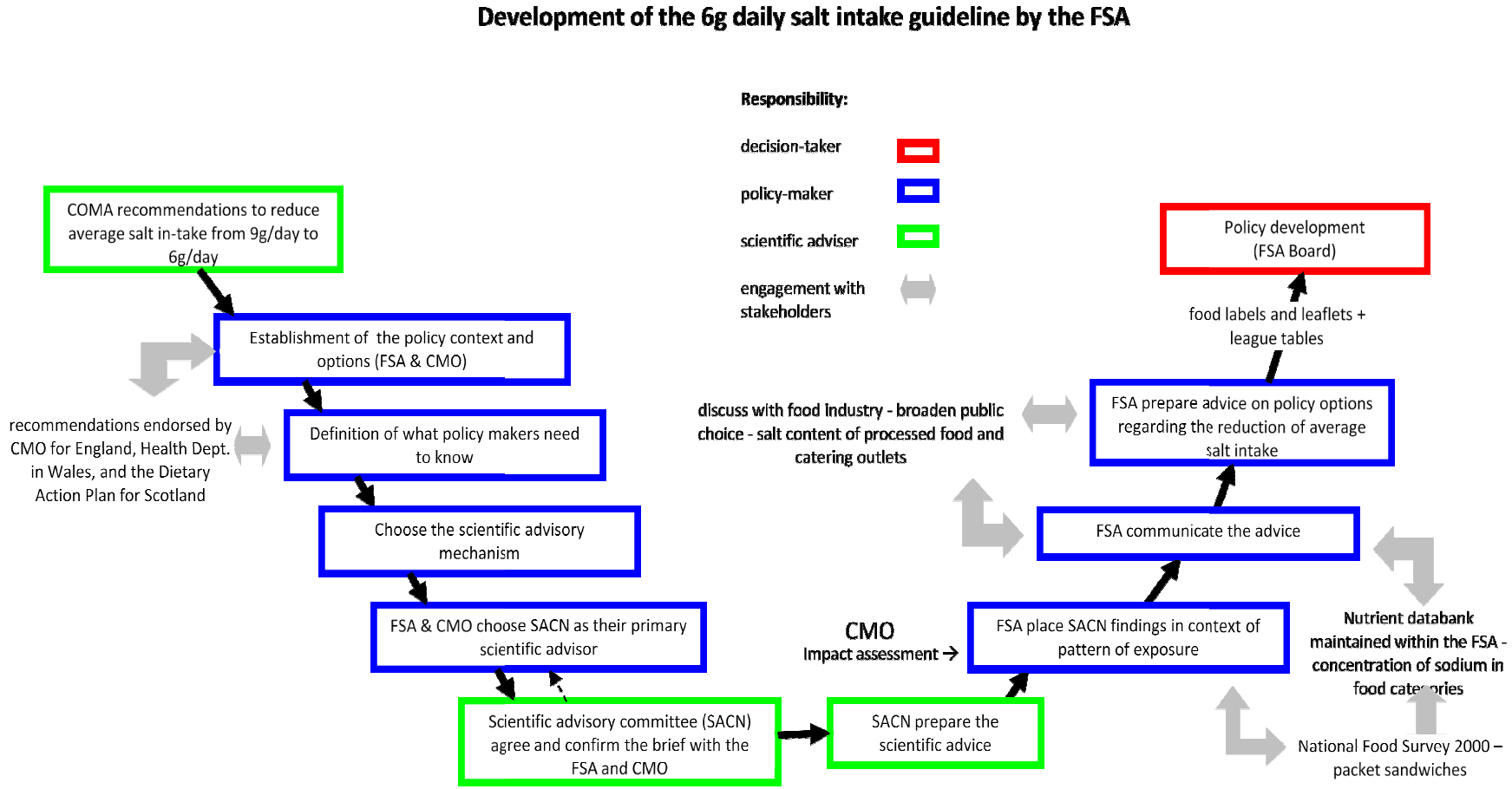


Figure 18: *Decision making process related to the Food Standards Agency's development of the 6 gram per day salt intake guideline*.

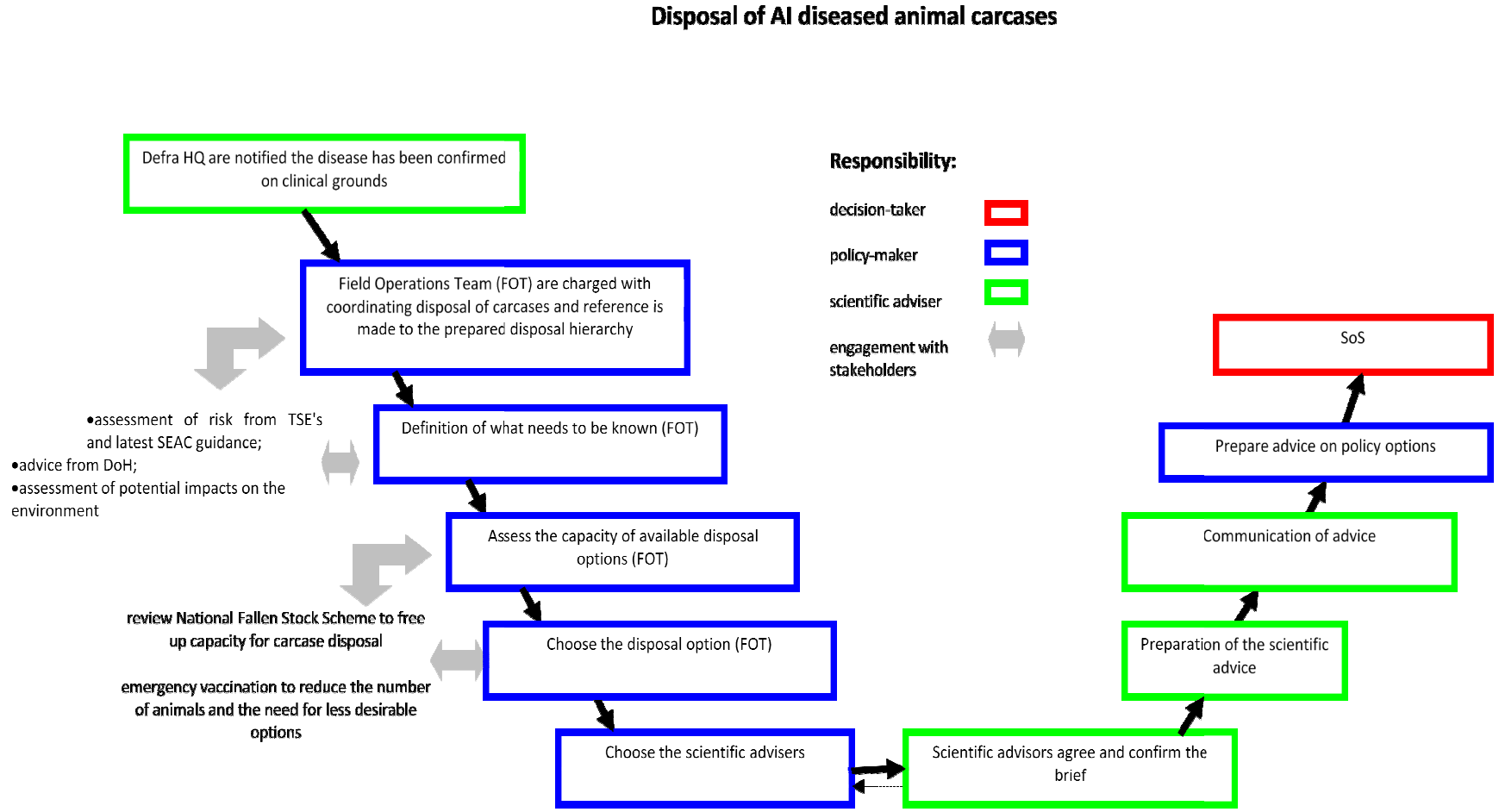


Figure 19: *Decision making process related to the Department of Environment and Rural Affairs coordinated effort for the disposal of avian influenza infected animal carcasses*.

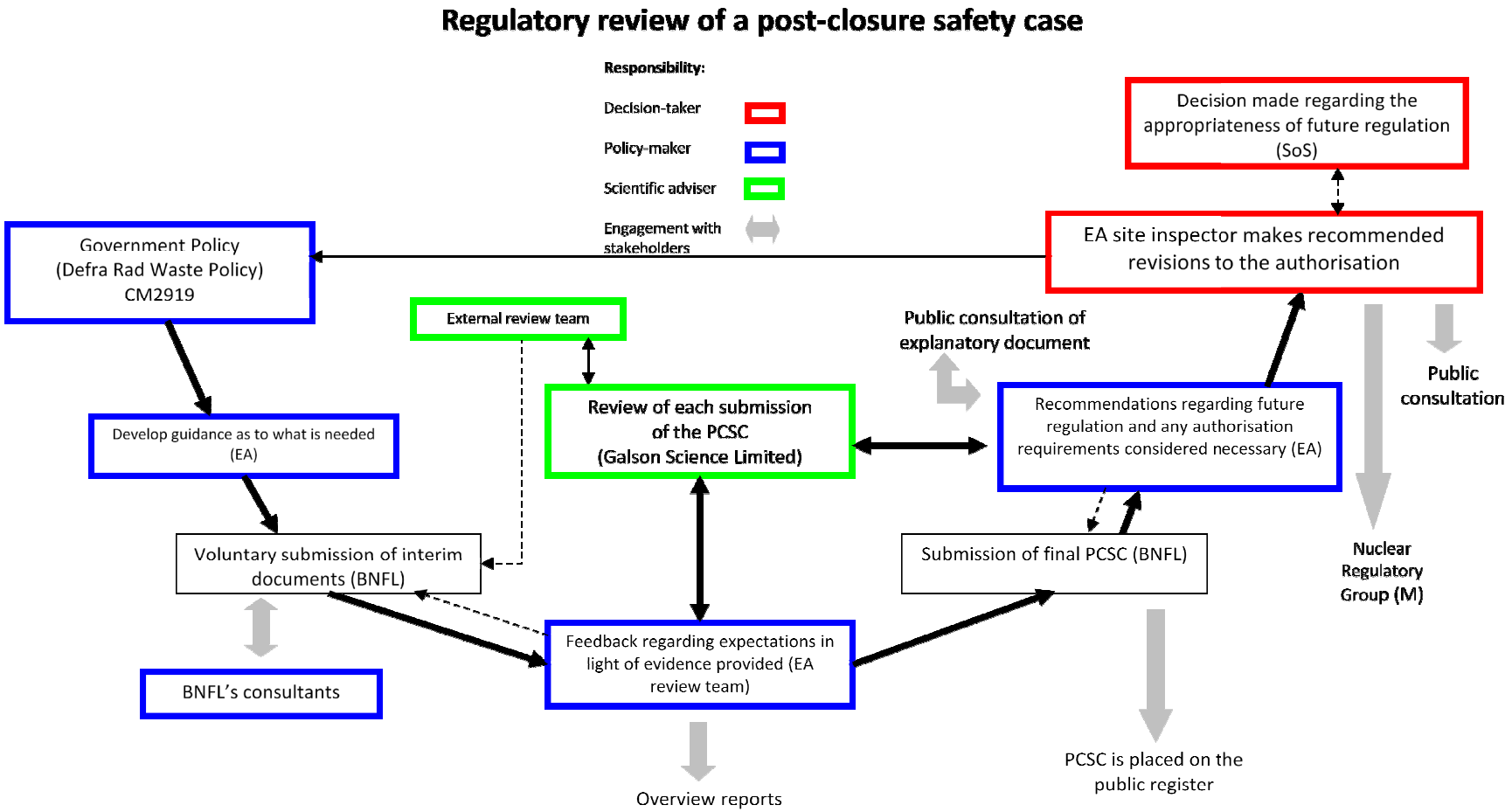


Figure 20: *Decision making process related to the Environment Agency's assessment of a post-closure safety assessment*.

Mapping out each decision using the methodology set out by OXERA (2000) was successful in capturing some key differences of the brokering process within each case study. However, the mapping out of the brokering process in this way was limited to the extent that it could show participants' influence.

Scientific advice, for example, is seen to play a different role in the nuclear waste case study compared to the salt intake and avian influenza case study. Scientific advice in the salt intake and the avian influenza case study is the first link in the chain of events. It also serves as a fundamental link, later in the process, between the policy makers and decision takers acting as a gatekeeper to the decision-taker. Figure 18 illustrates that if the science did not exist in the salt intake case study, for example, then it could be assumed that this would render the brokering process void. Hence, capturing the fact that the risk associated with salt intake is a risk of exposure and the risk associated with the nuclear waste disposal case study is a risk of an initiating event.

The other fundamental difference between the three case studies is the role played by stakeholder representatives. In the nuclear waste case study, stakeholders are not consulted until later in the brokering process (Figure 20). In the avian influenza case it was the opposite situation (Figure 19). In the salt intake case study, stakeholder representation is present throughout the brokering process (Figure 18). This depicts the fundamental difference in focus. In the former, the regulator had to build a case for support before it could be evaluated. In the avian influenza case, much of the work involving stakeholder consultation, was carried out ahead of a disease outbreak. In both of these case studies stakeholders were used as a quality control, but in the salt intake

stakeholder representation played more of a strategic role, increasing the chance of developing a policy that could successfully encourage food manufacturers to comply to voluntary standards.

In summary, the exploratory stage was successful in the selection of three case studies, mapping-out of the flow of information within each case study and establishing an understanding of the dynamics of the brokering process. The brokering process was found to consists of three stages; the receiving stage, the processing stage, and the passing-on stage. To achieve this, a comprehensive review of government reports, peer reviewed journal articles and grey literature found on the Internet was carried out. Using an existing methodology developed by OXERA (2000), a map representing the flow of evidence was created for each case study. The value of carrying out the exploratory stage was the insight this provided for conducting the semi-structured interviews and developing the research framework presented in the proceding chapter.

This page is intentionally blank

Chapter 6

DESCRIPTIVE STAGE

6.1. Chapter structure

This chapter presents the second stage of the data collection and builds on the insights gained by mapping out the logic behind the brokering of scientific evidence and its use for group risk-based decision-making. This addresses the first and second research objective. It models government risk-based regulation by carrying out semi-structured interviews to investigate three real-world case studies and develops a research framework capable of mapping out the logic of the brokering process. It is explained how the developed research framework is capable of exploring the influence participants have on the brokering of evidence.

6.2. In-depth semi-structured interviews

This section sets out the results obtained from carrying out semi-structured interviews. Figure 21 provides a connected account of the process by which insights abstracted from the exploratory stage informed the development of an interview schedules. These were used to carry out semi-structured interviews with one expert from each case study (i.e. the reduction of dietary salt intake, disposal of avian influenza infected animal

carcasses, and the development of a post-closure safety case for nuclear waste disposal). Interviews were recorded, transcribed verbatim, read, and reread to abstract heuristic codes that facilitated mapping out the process by which evidence was brokered within each case study. Heuristic code words (as apposed to objective codes) were used primarily as flags or signposts in the data and helped to identify queries from the transcripts. Query identified were cross-referenced with decision documents characterising each decision.

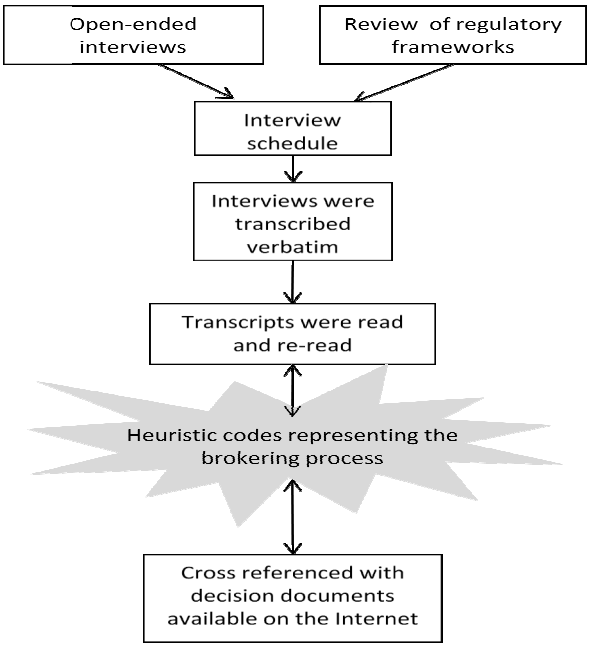


Figure 21: Connected account of the process followed to develop a semi-structured interview schedule, record, transcribe and abstract heuristic codes representing the process evidence in brokered in each case study.

The remainder of this section presents the results from carrying out the semi-structured interviews. This opens with a description of the flow of evidence in each decision as it was explained by the expert. This is complemented with the results obtained by asking

experts to map out theirs (and other) role in the brokering process. Finally, the queries abstracted from the interview transcripts are presented.

Respondents gave valuable insight into the flow of information; external process, points of entry, internal process, and actual decision. Talking generally about the brokering process they gave a comprehensive description of the flow of information and how it mattered different amounts within each case study, reflecting the difference that the brokering of evidence has to play for policy development, environmental planning and regulatory decision-making.

The external flow of information mattered most for the Environment Agency. Their role was to supervise the operator and ensure that the operator could demonstrate that sufficient evidence and knowledge was being taking into account for the characterisation, assessment, and management of risk. The regulator's role was to engage in dialogue with the operator and device the best means of obtaining the required evidence. Having said this, the regulator was not in a position to tell the operator what evidence to submit. This required the Agency to engage in dialogue with the operator to come up with an agreeable means of obtaining the required information. Keeping submissions of information confidential was an important requirement for the operator. The respondent explained that:

> "*... after a long dialogue eventually we said okay, we'll agree to a programme of submissions informally under this draft interim work in progress, which they said would allow them to be more open and honest about what they were giving us.*"

During this period of informal submissions, the operator (and their consultant) would submit evidence and knowledge. A relevant review group (containing Agency staff and their consultants) would then assess each submission and produce a number of issue resolution forms, outlining to the operator what outstanding issues needed to be resolved. The Agency required the operator to be open and honest about what they knew. However, the Agency also required the operator to understand what type of information was required of them. For example, one issue that was persistent during this dialogue was the issue of carrying out an independent peer-review before submitting evidence and knowledge. The operator did eventually get around to doing this but it came too late in the day to have any real affect on imbuing the Agency with any real confidence. In this respect, the respondent explained:

> *"it was really too late for it to have been any use to us. Again, that was one argument, one comment that we continued to give them right from the 1997 stage was we really recommend you carry out an independent peer."*

Hence, the Agency had the opportunity to engage in consultation with the operator but this did not guarantee that submissions of evidence and knowledge would come in the correct shape and form.

In addition, during this period of informal submissions, the Agency had the struggle of maintaining the correct balance. The Agency role was only to advise the operator of what issues the operator had not covered and possibly should address. Hence, the Agency had an idea of what the evidence would look like but because of the level of uncertainty surrounding risks being assessed it was imperative that the regulator keep a

reasonable distance and avoid biasing what evidence eventually got submitted. At times, however, this was misunderstood. For example, the respondent explained:

> *"I think they were almost using us as an independent peer reviewer and – they actually said but you're doing the peer review and we say no we're not, we're undertaking a regulatory review which is very different."*

As a result, the Agency (to overcome misunderstandings) would become frustrated with the operator always getting it wrong. On one occasion, the respondent explained that this required talking to someone with more power, because eventually if the regulator said too much they began to determine what evidence they would receive.

> *"You can't be holding the operator's hand in a way unless we really had a concern…*

Having said this, the regulator was also willing to direct the operator if the situation arose, but this was said to only apply if it was absolutely necessary.

> *"There were a few lines that we were absolutely fed up of keep reiterating ourselves and at the end of the day we did call a meeting at a more senior level and literally just sat around and spelt it out … he could see our point immediately"*

What the Agency eventually did with the info before formally processing it:

> *If you can imagine what we had from the project was a huge amount of documentation from these review groups so key scientific experts on our side giving their opinion on scientific knowledge that they'd been presented with but*

not all that was equally relevant. It's there and all the issue assessment forms are there, there's a lot of detail in those but what we did was distil those into key lines, key issues which we pooled into that overview report.

This required the Agency to eventually change the requirement to a formal submission of an overview report. This also presented the Agency with the issue of receiving the type of information that they were able to cope with.

Yet in reality, allowing the operator greater flexibility resulted in misunderstandings over the type of information that was required. Referring to this period of informal submissions, the respondent explained:

"*the programme dragged on, things were changed, the goalposts moved, we were working with the costs of the changing programme*"

The respondent explained further that eventually this all came to an end and the requirement for a submission of a PCSC changed from an informal to a formal submission.

However, the respondent explained that it was not their position to tell the operator what evidence and knowledge they should submit. Yet, it was their role to improve the chances that eventual submissions of evidence and knowledge would be of sufficient quality to imbue the Agency with confidence, the interviewee explained;

They said that if things done under the authorisation had to be public it would be more difficult to present the warts and all"

Initially, the Agency agreed to a series of informal submissions to allow the operator to be open and honest. Encouraging respondents to talk more specifically about the complexities and nuances that characterised the brokering of evidence, respondents were asked to split the decision into three distinct stages along a time line (Figure 22, 23 & 24). Referring specifically to this time line respondents were asked to explain in as much detail as they were capable on what occasions were they personally, or others, involved in the brokering of evidence. Then, to account for the influence different types of evidence had, as it passed through the stages of the decision, respondents were asked to score the weight political, social, cost, technical, qualitative and quantitative evidence would have. The relative influence each type of evidence had at different stages of the decision is illustrated in Figure 22.

Next, the "personal role" of those involved in the brokering process was investigated in greater depth. Respondents were asked to explain what role different participants had, what type of evidence they brokered, what weight these different types of evidence had (Figure 22, 23 & 24). In each identified phase the author asked the respondent a series of questions characterising: participants' involvement; the evidence and knowledge brokered; and the actions participants had to carry out.

Finally, in the latter stage of the interview the author asked a general question regarding the role they perceived risk-based approaches had to play in past, current and future regulatory decision-making. The aim was to give respondents the opportunity to talk more generally in the hope that this would spark further discussion about the importance of risk-based regulation and the brokering of evidence and knowledge.

The following figures illustrate the stages that the experts split the decision into. It can be seen that there are no values assigned to the types of evidence in the salt intake case study. This was a consequence of the respondent not having first hand experience of brokering evidence.

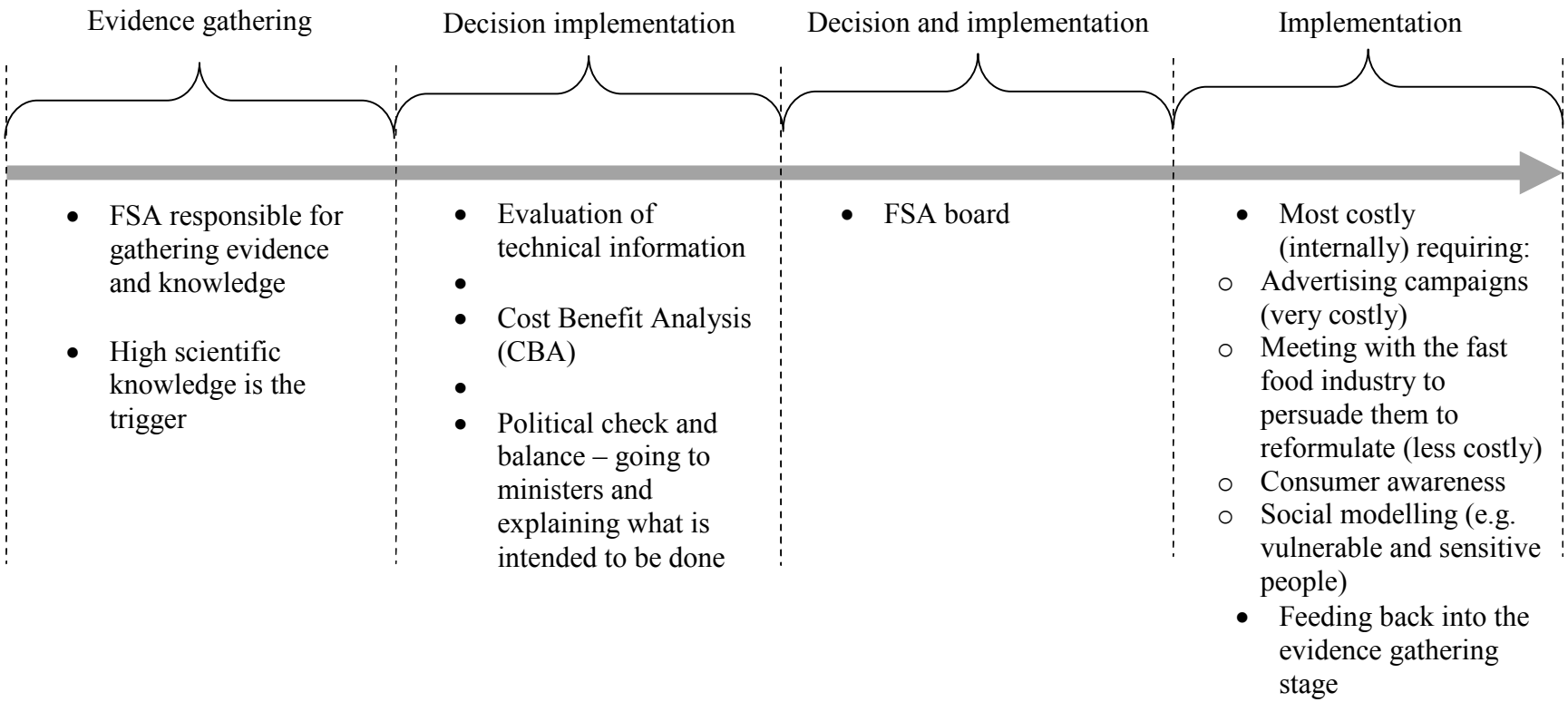


Figure 22: Different stages of the brokering process characterising the dietary salt intake case study

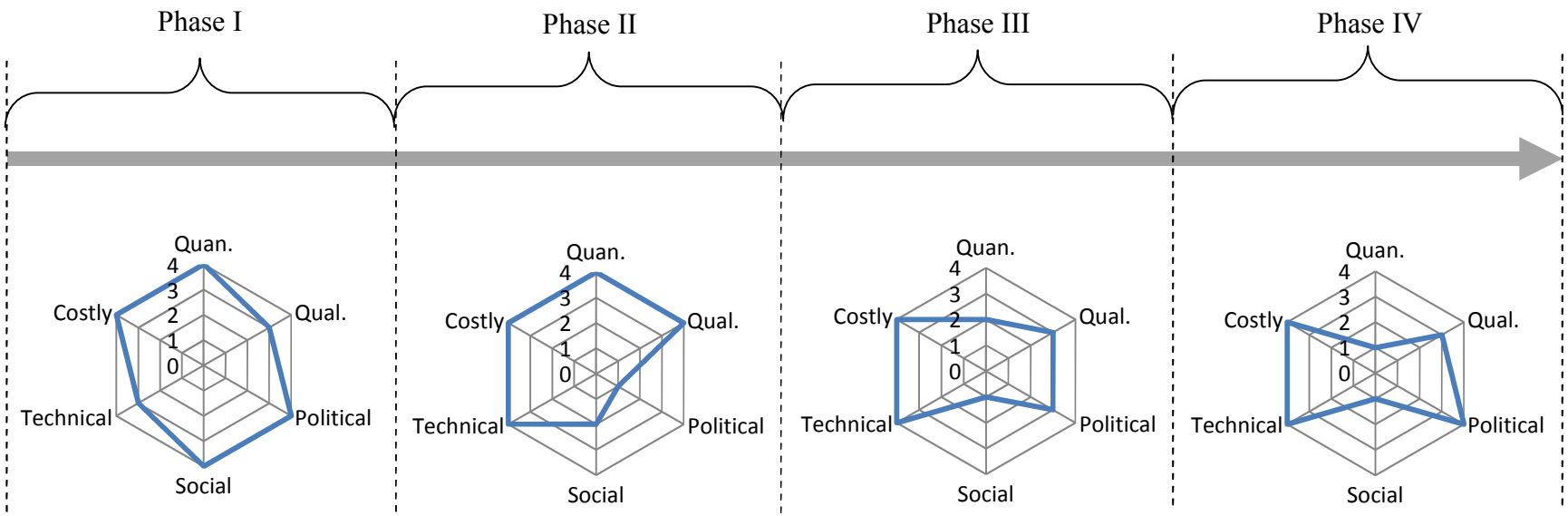


Figure 23: Different stages of the Environment Agency's regulatory decision whether to continue Driggs license to dispose of nuclear waste.

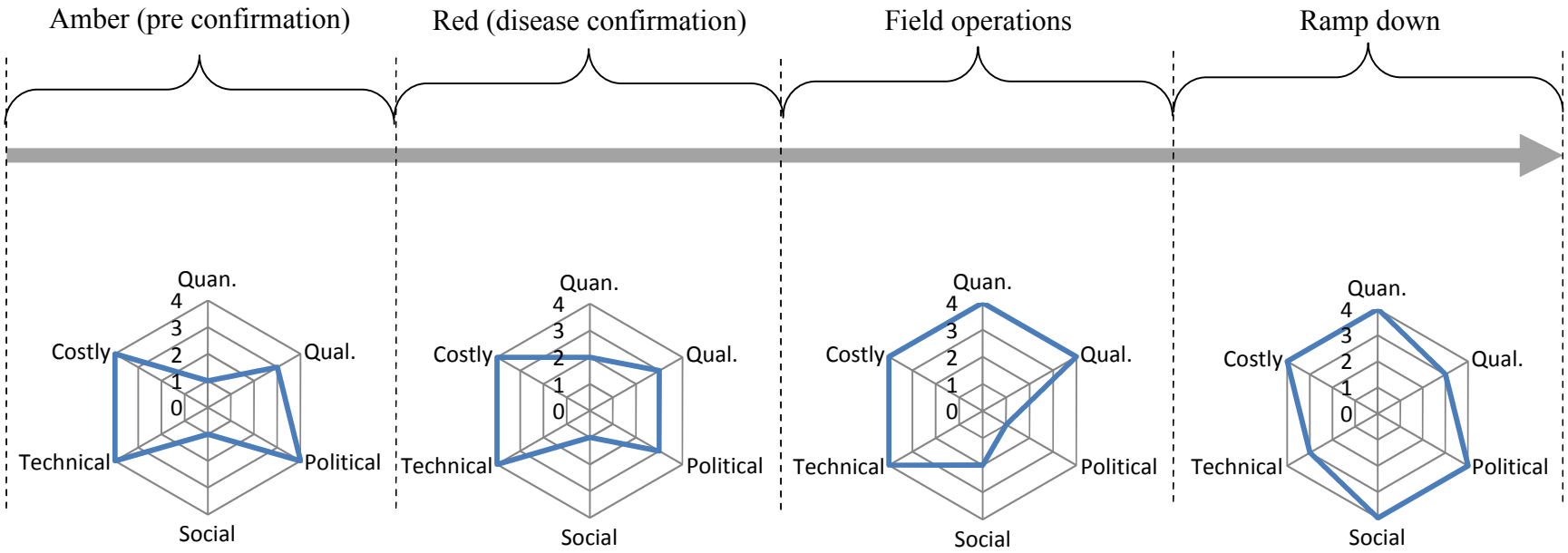


Figure 24: Different stages of the Department for Environment, Food and Rural Affairs disposal of diseased animal carcasses case study.

As a means of identifying what actions were available to the provider and the recipient in each stage of the brokering process in each case study, the scores set out in Table 2 & 3 were provided by the expert from the avian influenza and the salt intake case study. However, the expert from the nuclear waste case study felt that they did not have sufficient knowledge to provide this information.

Table 2 illustrates the regulatory actions that were said to be available to the regulator within the avian influenza case study. This is in contrast to the actions at the regulators disposal in the nuclear waste case study. In the nuclear waste case study, the regulator had the role of supervising the operator and what evidence they might submit. In the avian influenza case study, on the other hand, the regulator made specific requests on what types of evidence the regulator should submit and had coercive power to ensure this would happen.

Table 2: Applicable actions for the Defra receiving and passing-on of evidence and knowledge at each stage of the decision, as described by the respondent

Actions:	**Amber (pre confirmation)**		**Red (disease confirmation)**		**Field operations**		**Ramp down**	
	R	**P**	**R**	**P**	**R**	**P**	R	P
no action					X	X		
Inform	X	X	X	X	X	X	X	X
Educate	X	X	X		X	X		
Advice	X	X	X	X	X	X		
Guide	X	X	X	X	X	X		
Influence			X	X	X	X		
Encourage				X	X	X		
Persuade				X	X	X		
Instruct			X	X	X	X	X	X
Direct			X	X	X	X	X	X
Warn			X	X	X	X		
Threaten				X	X	X		
Sanction					X	X		
Enforce			X		X	X		
Prosecute					X	X		

Table 3: Applicable actions for the FSA receiving and passing-on of evidence and knowledge at each stage of the decision, as described by the respondent

	Stage 1		**Stage 2**		**Stage 3**		**Stage 3**	
Actions:	**R**	**P**	**r**	**P**	**R**	**P**	R	P
no action								
Inform								
Educate								
Advice								
Guide	X		X		X		X	
Influence	X	X	X	X	X	X	X	X
Encourage	X	X	X	X	X	X	X	X
Persuade	X	X	X	X	X	X	X	X
Instruct	X		X		X		X	
Direct								
Warn								
Threaten								
Sanction								
Enforce								
Prosecute								

During these follow-up interviews, experts were asked to validate the logical way in which queries were laid out. Then experts were asked to assign a weight (between 0 and 1) to reflect how sufficient each "child" query was for answering its corresponding "parent" query (referred to in greater detail in the proceeding section).

This illustrates how the each decision, characterising each case study, can be broken down into consecutive chains of supporting "child" and "parent" queries. Each consecutive string of queries represents a single line of evidence supporting the central decision being made in each case study.

Each case study takes on a different form. The nuclear waste case study is the most technical and has the structure of an audit. The salt intake case, however, takes on a

much more intricate framework than the others. The lines of evidence are far stretching and involve a large number of separate groups. The lines of consecutive queries are not as structured as in the nuclear waste or the avian influenza case study. The avian influenza case study again is more rigid than the salt intake but less than the nuclear waste case study.

After carrying out semi-structured interviews with experts, the author abstracted narratives regarding participants' involvement in the brokering of scientific evidence and knowledge. These narratives provided insights into personal features that influence participants' evaluation of evidence and knowledge. These factors included the existence of informal communication networks, the impact of positive and negative prior knowledge, the impact a participant's attitude toward those providing the information had on their evaluation of its sufficiency etc. Moreover, placing these in the context of the brokering of scientific evidence and knowledge, respondents discussed the relative influence economical, political, social and technical factors had on the receiving, processing and passing on of information. Hence, the content of these narratives provided insights that were not accessible through Government reports or peer reviewed literature. Therefore, despite the limited access to experts, conducting in-depth interviews provided the author with access to valuable insights regarding the dynamics of the brokering process that supports real world risk-based group decisions.

Chapter 3 critically assessed the current state of knowledge regarding the influence power structures and personalities have on group decision making, and specifically how participants influence decision outcomes through the act of knowledge sharing. To

achieve this, the author mapped out the hierarchical relationship representing the manner in which power structure and personality traits influence the receiving, processing and passing on of evidence and knowledge

.

This section has presented the results from carrying out the semi-structured interviews. The semi-structured interviews were successful at obtaining the depth of information required to describe the nuances characterising the brokering process. Access to respondents was limited to carrying out a one hour interview with each expert. Mock interviews were carried out to prepare for this. However, these interviews took longer to administer than was expected. Moreover, the expert consulting on the salt intake case study had not been directly involved in the decision making process and therefore was not able to provide the level of detail that the expert from the other two studies were. However, the expert did have extensive knowledge of the directional flow of evidence, relative accountabilities and was able to offer general insights into the influence participants play in the brokering process.

A number of differences exist between the case studies. It was shown how the brokering process characterising each case study varied by the amount of time spent on the brokering of evidence. The nuclear waste case study, for example, took up to four years to play out. The regulator underwent extensive dialogue with the operator, passing through a period of voluntary submissions followed by a formal review. Conversely, the avian influenza case study was characterised by emergency response, and as such had very little time to engage in dialogue with the operator. The regulator had to rely on the prior knowledge they had regarding the operator and act quickly in response to any new

negative knowledge they received. The salt intake case gave the regulator a greater level of discretion to engage in dialogue with the operator compared to the avian influenza case, but their ability to pass-on their belief was severely restricted by their lack of legitimate, coercive and reward power.

6.3. Development of the research framework

This section explains how an existing framework was developed to model the influence participants had on the brokering of evidence.

Evidence-support logic (ESL) was used to map out how a number of lines of evidence that informed a group decision. Conventionally, this framework has been used to model the influence relative degrees of uncertainty have for informing an overall measure of confidence. It breaks down a central hypothesis into consecutive chains of supporting "parent" and "child" hypotheses. Building upon interval probability theory developed by researchers at Bristol University (UK), ESL propagates beliefs "for" and "against" from a supporting child hypothesis to a corresponding parent hypothesis (Feller, 1971; Cui and Blackley, 1990; Hall et.al 1998). It does this by taking the sum of belief for and against and subtracting them from the value of one ((i.e. $p + q + u = 1;\ 0 \leq p, q \leq 1\ and - 1 \leq u \leq 1$), where p = belief for, q = belief against and u = uncommitted belief). The result is a triple measure of probability that can account for the influence of uncertainty as a measure of uncommitted belief.

Figure 25 illustrates how this logic has been mapped out within TESLA, an existing software developed by risk specialists Quintessa. It can be seen that the measure of uncertainty characterising a belief is sometimes represented as a negative value and sometimes represented as a positive value. Positive values represent the degree of absent belief and negative values represent the degree of conflicting beliefs. Either way, for the purposes of mapping out the brokering process in this thesis, uncommitted belief is taken to be a direct measure of uncertainty characterising the submitted evidence.

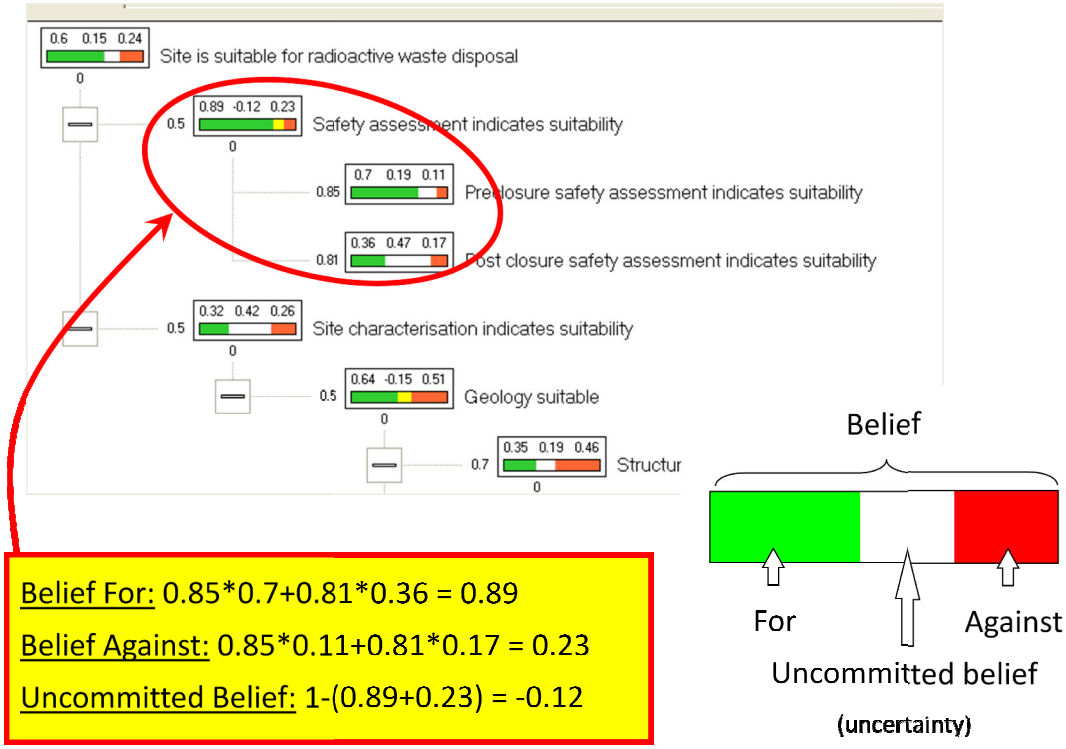


Figure 25: TESLA™'s use of evidence support logic (ESL) to represent how a number of lines of evidence (LOE) inform a group risk-based decision *(http://www.quintessa-online.com/TESLA™/)*.

Figure 26 presents the math supporting the aggregation of beliefs. In short, the logic states that parent hypotheses are assigned weights (between 0 and 1) to reflect how

sufficient, dependent and necessary each subordinate child hypothesis is for answering its hypothesis. These weights are multiplied against subordinate beliefs "for" and "against" as they are propagated. Weights reflecting necessity reflect that the absence of a belief being formed for a necessary child hypotheses is reflected by the parent hypothesis failing to form a belief. Weights reflecting dependence, on the other hand, state how dependent two or more child hypotheses are for forming the parent hypothesis. This is calculated by multiplying the minimum of the two beliefs "for" or "against" and subtracting the end product from the greater of the two. Sufficiency, on the other hand, reflects the proportion that the child hypothesis can address the parent hypothesis.

Let (p_A, u_A, q_A) denote the aggregated belief. It can be computed as follows.

$$p_A = \sum_{i=1}^{n} w_i p_i - \sum_{\substack{i,j=1 \\ i<j}}^{n} \rho_{ij} \min(w_i p_i, w_j p_j) + \sum_{\substack{i,j,k=1 \\ i<j<k}}^{n} \rho_{ijk} \min(w_i p_i, w_j p_j, w_k p_k)$$

$$+ \ldots + (-1)^{n-1} \rho_{1,\ldots,n} \min(w_1 p_1, \ldots, w_n p_n) \quad (1)$$

where, if $S = \{i, j, \ldots\}$,

$$\rho_S = \frac{(1-D)\prod_{a \in S} w_a p_a}{\min_{a \in S}(w_a p_a)} + D$$

Here w_i is the weighting of the i^{th} line of evidence; D is the dependency between the evidence $p_i, p_j, \ldots, p_n$. The computation of q_A is then similar to (1).

$$q_A = \sum_{i=1}^{n} w_i q_i - \sum_{\substack{i,j=1 \\ i<j}}^{n} \rho_{ij} \min(w_i q_i, w_j q_j) + \sum_{\substack{i,j,k=1 \\ i<j<k}}^{n} \rho_{ijk} \min(w_i q_i, w_j q_j, w_k q_k)$$

$$+ \ldots + (-1)^{n-1} \rho_{1,\ldots,n} \min(w_1 q_1, \ldots, w_n q_n) \quad (2)$$

where $\rho_S = \frac{(1-D)\prod_{a \in S} w_a q_a}{\min_{a \in S}(w_a q_a)} + D$.

u_A can be determined by means of $p_A + q_A + u_A = 1$ once we have the values of p_A and q_A. Specially, when $n = 2$ and beliefs 1 and 2 are independent, we have,

$$\begin{cases} p_A = w_1 p_1 + w_2 p_2 - \max(w_1 p_1, w_2 p_2) \min(w_1 p_1, w_2 p_2) \\ q_A = w_1 q_1 + w_2 q_2 - \max(w_1 q_1, w_2 q_2) \min(w_1 q_1, w_2 q_2) \end{cases}$$

Figure 26: Maths behind evidence support logic (Li, Unpublished)

Using this logic set out in ESL, TESLA has been able to provide an audit trail of beliefs in the sufficiency of supporting evidence. As such, it has gained a history of being used to map out the logic of risk-based decision-making (Foley et al., 1997; Hall et al., 1998). Such examples have shown the value it has for demonstrating the implication that different sources of evidence can have for informing an overall belief. Moreover, it gives the user the capacity to carry out sensitivity analysis to show which lines of reasoning (with their relative values of sufficiency, necessity and dependency) are particularly susceptible to changes in uncommitted beliefs assigned to bottom level hypotheses.

To date it has provided support for a number of regulatory decisions such as the long term geological storage of carbon dioxide (Benbow, 2006) and the disposal of radio active waste (Seo et al., 2004). In this context, TESLA provided a means of transparently divulging the weights to supporting a central hypothesis, representing how the evidences fitted together and the relative influence measures of uncomitted belief had on the relative measure of confidence that could be assigned to a central hypothesis.

TESLA's use of ESL offer the user a means of improving the transparency of risk-based decisions by recording the structure, sufficiency, dependency and necessity of supporting lines of evidence. It has been reported to have a number of advantages in this regard, building confidence and facilitating the communication of logic supporting risk-based decisions.

However, as it stood, the use of TESLA assumed that weights reflecting sufficiency, dependency and necessity were universally set out. That is, these relative weights were the end product of experts reaching a concensus. In a similar fashion, weights assigned to each query in the research framework were assumed to be informed by government guidance. However, these were merely used as a reference point that could be updated as the decision went live, and practitioners made value judgements regarding the sufficiency of submitted evidence.

It is suggested the framework set out in evidence-support logic could be applied to modeling the influence participants have on the brokering of evidence by the extent that they would modify the values of sufficiency.

Chapter 6 illustrates how queries were identified from narratives captured in the semi-structured interviews. The author mapped out the series of questions representing the group decisions for each case study and explained how follow-up interviews were carried out with experts. Here it is explained how the research framework assumes that sufficiency starts off as a pre-determined value (set out in guidance, for example) but is modified by participant's power and personality as agents (people) interact. Then through the follow-up interview with each expert, the author gained access to predetermined values of sufficiency. Through the development of a power and personality model, an additional weighting factor multiplied to the pertinent value of sufficiency represents the influence participants have in determining the weight different lines of evidence will have on the group decision outcome.

During the interviews experts were asked to validated the logical sequence of queries and attributed weights (between 0 and 1) to reflect how sufficient each "child" query was for answering its corresponding "parent" query. Experts also gave a proportional value that reflected the amount of belief that they would normally be expected to be available for answering each bottom-level query (otherwise referred to as a "leaf" hypothesis). All this was mapped out within the research framework and explained how it would be possible to add weight to reflect the influence that power and personality has on recipient's receptivity, by taking account of known power and personality influences.

Aforementioned, TESLA™ assumed that a single expert, or group of experts, reached a consensus on how sufficient, dependent and necessary each 'child' hypothesis was for addressing its corresponding 'parent' hypothesis. This was not the case in this thesis. This thesis assumed that each hypothesis represented a query characterising a decision participant's role. As such, a weight reflecting the sufficiency of a 'child' query for answering a 'parent' query depended on how receptive they were to the participant passing-on the evidence and knowledge. To account for this, the author created the following hierarchical model of agent's receptivity that could complement evidence-support logic to account for the influence of the individual, where known power structure and personality factors were organised (Figure 27).

Receiving stage:

- Recipient's propensity to trust
  - Extroversion
  - Neuroticism
  - Agreeableness
- Recipient's willingness to engage in interpersonal trust
  - Positive prior knowledge
  - Negative prior knowledge

Processing stage:

- Recipient's legitimate power
  - Permissible consultation period
- Recipients motivation to systematically and carefully process information
  - Openness to experience
  - Level of uncertainty
    - Indeterminacy and/or ignorance.

Consultation stage:

- Provider's motivation to systematically and carefully process information carefully
  - Level of uncertainty
    - Indeterminacy and/or ignorance
  - Openness to experience
- Provider's trust worthiness
  - Agreeableness
  - Conscientiousness
- Provider's propensity to trust
  - Extroversion
  - Neuroticism
  - Agreeableness
- Recipient's trustworthiness
  - Agreeableness
  - Conscientiousness
- Provider's willingness to engage in interpersonal trust
  - Positive prior knowledge
  - Negative prior knowledge

Figure 27: Logic supporting the influence power structure and personality has on the brokering process (the receiving, processing and passing-on of scientific evidence and knowledge.

Next, conditional weights were assigned to each factor within the hierarchy set out in Figure 27. Then propagation of values (reflecting a low, medium or high presence of each bottom level factor) through the hierarchy, gave an overall value between zero and one, reflecting the recipient's receptivity (Figure 28). It was assumed that recipient's receptivity was a product of all three stages unless the recipient lacked legitimate power to engage in consultation, in which case, recipient's receptivity was only a product of the receiving and processing stage.

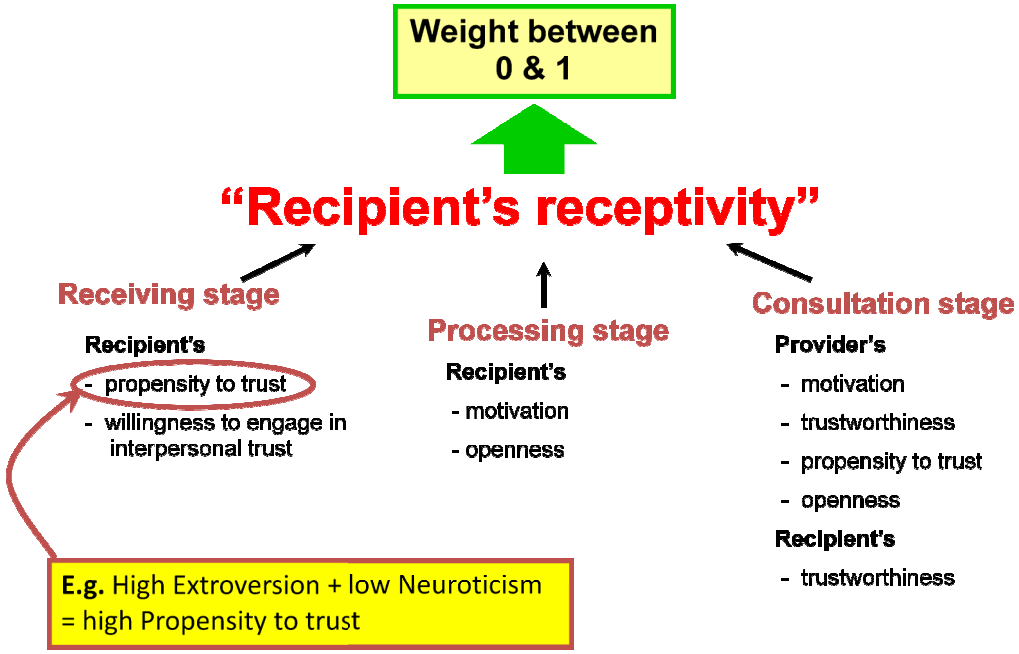


Figure 28: The logic set out to calculate recipient receptivity.

Calculating a recipient's receptivity weight permitted the evidence-support logic framework to be developed to reflect the influence participants had on the group decision. Weights reflecting recipient's receptivity were multiplied against weights reflecting sufficiency (Figure 29).

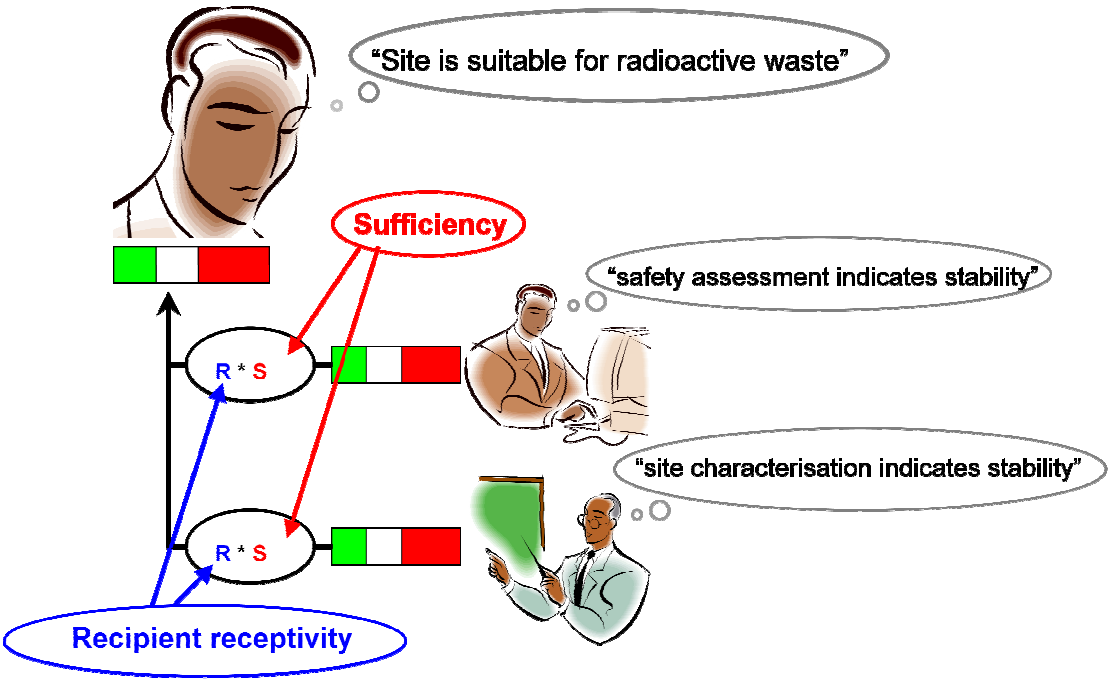


Figure 29: Logic behind incorporating power structure and personality influences within the research framework.

Having come up with a way of developing the existing evidence-support logic framework the semi-structured interviews transcripts were analysed by breaking down the central decision, representing each case study, into a number of parent and child queries (Figure 30, 31 & 32).The author then carried out a follow-up interview with each expert. During these interviews experts were asked to validate (and where necessary elaborate) on the logic of each of these schematics. Experts were also asked to allocate a weight (between 0 & 1) to reflect how sufficient and necessary each child query was for answering its corresponding parent query. Finally, experts were asked to state what proportion of evidence they expected to be available for answering each bottom level child query.

The FSA Board agree that action should be taken

- *Public consultation:*
  - *Does anyone have evidence to oppose the board's action*
- *SACN (Salt Team):*
  - *Cost Benefit Analysis:*
    - *Is it appropriate if it is going to drive a whole sector of the food industry*
    - *Is it appropriate if it is only going to save one life*
    - *Is it achievable*
  - *What is the most appropriate mechanism for achieving a reduction in salt intake*
    - *The most appropriate mechanism is through working together with food manufactures to reformulate their food*
      - *SACN (Salt Team):*
        - *Impact assessment (Better Regulation Team)*
          - *Should the food industry reduce the level of salt in their food products*
            - *What would be the cost of trying to achieve 6 grams per day*
              - *The food industry will not transfer the cost of regulation over to the customer*
              - *The food industry could sustainably bear the cost of the required action*
            - *Could the food industry actually achieve target levels*
            - *What impact are industries own attempt to address the issue*
        - *Is the food industry willing to change their behaviour*
          - *Do they see the writing on the wall*
    - *The most appropriate mechanism is through an educational campaign*
      - *SACN (Salt Team)*
        - *Impact assessment (Better Regulation Team)*
          - *Should the general public reduce salt levels used in their eating habits*
            - *Can people actually achieve 6 grams per day*
              - *What is the best way of influencing the food industry to reformulate*
                - *Leaflets are an effective means of communicating with the public*
                - *Food labels are an effective means of communicating with the public*
                - *League tables are an effective means of communicating with the public*
              - *Are they the cause of exposure*
        - *Are individuals willing to change their behaviour*
  - *Is 6 grams per day an appropriate level?*
    - *There is reason to believe salt intake poses a risk (SACN)*
    - *What research is out there (Policy team – horizon scanning)*
      - *Salt is an issue and it needs to be considered*
        - *COMA recommend that average salt intake should be reduced to 6 grams per day*
        - *Others endorse the claim that salt intake should be reduced to 6 grams per day*
          - *Chief Medical Officer for England*
          - *Health Department in Wale*
          - *Dietary action for Scotland and Northern Ireland*
          - *Food industry*

Figure 30: illustrating the logic of Case Study 1 mapped out within TESLA™

Conditions and limitations for reauthorisation are reasonable and the SoS's do not require a full public enquiry to be carried out
- *The operator can ensure sufficient public and environmental protection to justify reauthorisation (Decision Document)*
  - *Public consultation suggests that the conditions and limitations for reauthorisation, set out in the explanatory document.*
  - *The operator can ensure sufficient public and environmental protection to justify reauthorisation*
    - *Sufficient conditions and/or limitations exist to justify reauthorisation (Overview Report)*
      - *The formally submitted PCSC sufficiently addresses all relevant review criteria*
        - *All guidance issues have been resolved during the management type meeting*
        - *All issues are addressed as being satisfactory at the scientific meetings*
          - *Operator has sufficiently addressed risks associated with gas*
          - *Operator has sufficiently addressed risks associated with disruptive events*
          - *Operator has sufficiently addressed risks associated with parameters*
          - *Operator has sufficiently addressed risks associated with cap*
          - *Operator has sufficiently addressed risks associated with assessment*
          - *Operator has sufficiently addressed risks associated with regulatory action*
          - *Operator has sufficiently addressed risks associated with assessment criteria*
          - *Operator has sufficiently addressed risks associated with OES*
          - *Operator has sufficiently addressed risks associated with engineering*
          - *Operator has sufficiently addressed risks associated with near field*
          - *Operator has sufficiently addressed risks associated with geosphere*
          - *Operator has sufficiently addressed risks associated with biosphere*
        - *Operator has understood and addressed all the relevant criteria set out in the GRA*
        - *All guidance issues have been resolved during the management type meeting*
        - *All issues are resolved at the scientific meeting*
          - *Operator has resolved all issues associated with gas.*
          - *Operator has resolved all issues associated with disruptive events*
          - *Operator has resolved all issues associated with parameters*
          - *Operator has resolved all issues associated with cap*
          - *Operator has resolved all issues associated with assessment*
          - *Operator has resolved all issues associated with regulatory action*
          - *Operator has resolved all issues associated with assessment criteria*
          - *Operator has resolved all issues associated with OESC*
          - *Operator has resolved all issues associated with engineering*
          - *Operator has resolved all issues associated with near field*
          - *Operator has resolved all issues associated with geosphere*
          - *Operator has resolved all issues associated with biosphere*

Figure 31: illustrating the logic of Case Study 3 mapped out within TESLA™

The outbreak of Avian Influenza will not pose harm to the environment, human health or animal health

- *Evidence/analysis/inspection suggests there is not any cause for concern*
  - *The clean-up and removal will not pose harm to the environment human health and animal health*
    - *The veterinary manifestations of the particular outbreak will not pose harm to the environment, human health and animal health*
  - *The animal carcasses are being disposed of according to plan – they are not stacking up posing harm to the environment, human health and animal health*
    - *The dead animal carcasses are not stacking up*
    - *The disposal of animal carcasses is going according to plan*
      - *The personal protective equipment is efficient and effective*
      - *Regulation suggests there is not any cause for concern*
      - *Premises of facility are still considered suitable after a specific protocol has been drawn up*
      - *Management of the facility is not posing a problem*
      - *No issues are raised by the trade association*
      - *Waste management is being carried out proficiently and according to plan*
  - *Animal carcasses are being transported to the facility*
    - *Dead animal carcasses are assigned to a disposal facility*
    - *Animal carcasses are being transported safely, with leak proof vehicles ADR trained drivers according to transport logistics, without harm to the environment, human health and animal health*
  - *The disposal of animal carcasses within the selected facility will not pose harm to the environment, human health and animal health*
    - *The facility, suggested by Animal Health, should be used for the disposal of infected animal carcasses*
    - *The facility is considered to be safe and there are no outstanding issues that suggest the facility*
    - *The facility does not pose a bio security risk*
      - *The Health Protection Agency are content that the facility will not pose a bio-security risk*
      - *The Environment Agency are content that the facility will not pose security risk*
      - *Animal Health are content that the facility will not an animal health risk*
    - *Divisional Veterinary Manager agrees to put in place a team to manage, oversee and supervise the disposal*
    - *The operator is content to have the business and are willing to sign a contract*
    - *The facility closest in proximity and/or capacity to the IP of the infected premises is selected*
      - *A number of suitable facilities are selected from the green list*
        - *The facility does not pose an unreasonable risk to public health – there not*
          - *A number of suitable facilities are selected from the green list*
            - *The facility does not pose an unreasonable risk to public health – there not.*
              - *According to the Environment Agency's regulatory interests.*
                - *The disposal facility is not being sued*
                - *There has not been a breakdown*
              - *According to the Environment Agency science base.*
            - *A PPC permitted category 1 & 2 ABP approved facility is available*
              - *Facility meet with the annual bio security requirements set out*
            - *Most appropriate disposal option is selected*
              - *Disposal hierarchy gives Animal Health and Policy contentment*
- *Outbreak confirmed and animals need to be culled*

Figure 32: illustrating the logic of Case Study 2 mapped out within TESLA™

6.4. Chapter summary and conclusions

This chapter has discussed the potential of deriving a weight to reflect power and personality within the developed research framework. Graphical outputs, similar to those provided by TESLA™ (e.g. Figure 33), may allow the end user to analyse areas of their decision-making that could benefit from further attention in order to reduce decision uncertainty and therefore, enable the relative influence that power structure and personality has on the resolution of uncertainty.

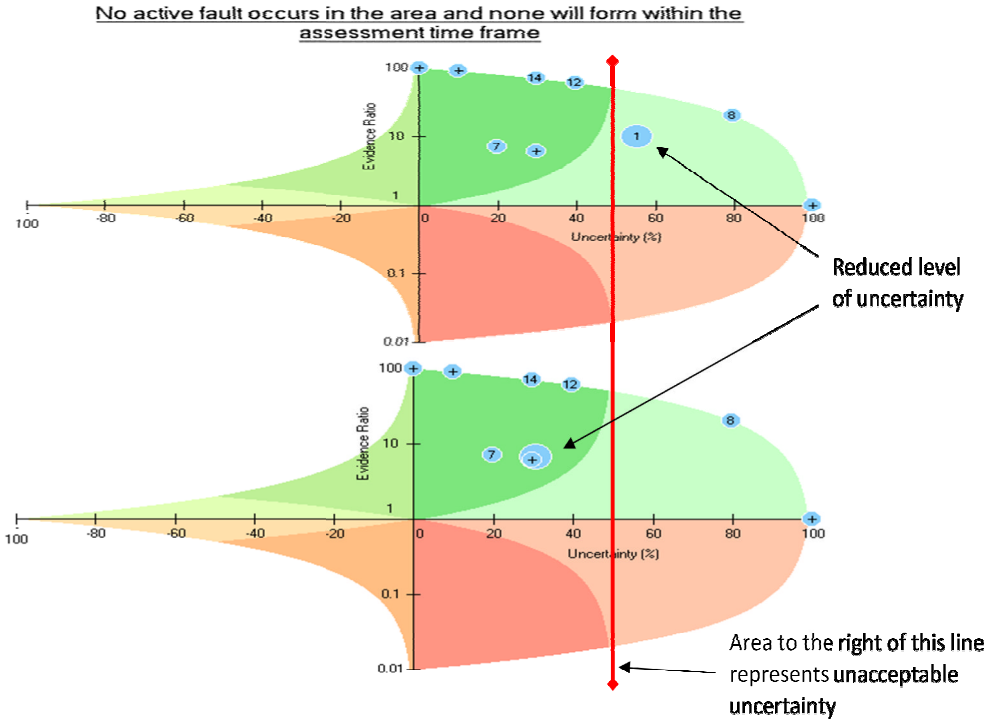


Figure 33: Ratio plot illustrating the difference when recipient's receptivity is accounted for (a) and when it is not accounted for (b).

This could enable the relative influence that power structure and personality has on the resolution of uncertainty.

The next chapter will describe the development of two-agent simulation model that can generates a measure of receptivity and confidence in the sufficiency of submitted evidence.

This page is intentionally blank

Chapter 7

MODEL DEVELOPMENT

7.1. Chapter structure

This chapter sets out how the author has incorporated findings identified in Chapter 2, 4 & 6 within an agent-based simulation model. It addresses the third research objective by investigating the possibility of developing an agent-based simulation model for representing interacting decision makers. It is explained how dialogue between agents can influence confidence building and value judgements regarding the sufficiency of submitted evidence.

Previous chapters of this thesis provide the foundation on which the following agent-based model has been developed. Unstructured interviews (in Chapter 4) were carried out with five regulators from the Environment Agency. These interviews described what influences the brokering process had, especially regarding participant's receptivity to scientific evidence presented.

Findings of the unstructured interviews confirmed that the brokering process consisted of a series of interactions between recipients and providers of evidence; for example, between a regulator and a leader, a consultant or an operator. These interviews informed the development of the agent-based model by providing an understanding of the nuances that characterise the dynamic nature of this brokering process. These interviews

also explained that people (agents) involved in the brokering process must pass through a receiving, processing and passing-on stage. A recipient who received information, dependent on his/her role, would place a value on it regarding its sufficiency before turning to pass it on to the next person in the brokering process.

The receiving stage consisted of the regulator asking, what information is available? The answer to this question depended on the context of the decision, their desire to know more and their position of authority. For example, how political the case was and how many people got involved. The regulator's access to internal and external networks (both formal and informal) determined the number of lines of evidence they were presented with. Moreover, if the regulator had sufficient legitimate power they had the discretion to investigate for more.

The processing stage consisted of the regulator processing the information he/she received. The regulator had to make value judgements regarding how credible or reliable they believed the submitted evidence to be. The regulator's perception of credibility regarding the operator and the scientific evidence influenced this. The outcome of judgements made regarding the sufficiency of the submitted evidence determined the belief regulators would attach to evidence before passing it on.

The passing-on stage was dependent on whether the regulator had the power to pass on the findings from the preceding stages. This depended on how contentious the decision outcome was and how trusted they were to make the right decision by those they were passing it on to. It was explained that this could result in the belief (with the supporting

evidence) being bounced back to the regulator, causing them to revisit the processing stage (and possibly the receiving stage) to reassess the sufficiency of the submitted evidence and possibly their belief. Experts explaining this process, stated that individuals play various roles in the brokering of evidence, similar to the work described by OXERA (2000).

Three case studies were selected to represent the different conditions in which scientific evidences was brokered in risk-based regulation. A review of available regulatory frameworks characterising decisions being made in risk-based regulation was carried out. Three decisions that represented a broad range of conditions in which evidence was brokered in risk-based regulation were selected. The three case studies selected were:

- The proposed reduction of dietary salt intake;
- The disposal of avian influenza-infected animal carcases; and
- The development of a post-closure safety case for nuclear waste disposal.

The directional flow of evidence and the roles individuals played in the brokering of evidence, in each case study, was pooled together and mapped out using a methodology described by OXERA (2000).

Semi-structured interviews were carried out with one expert from each case study. An interview schedule was designed based on the findings of the unstructured interviews and the review of available regulatory frameworks. Experts were asked to refer to the brokering process as three distinct stages, described in Figures 22, 23 & 24. Decisions

that had to be made in each stage were identified from narratives in the interview. These decisions were structured according to the framework set out by evidence-support logic.

Mapping out the brokering process consisted of mapping out the logical sequence of "child" and "parent" queries that supported the central query characterising each case study. Chapter 6 also explains how a follow-up interview was carried out with each expert interviewed in each case study. During these follow-up interviews experts validated the logical sequence of queries and attributed weights (between 0 and 1) to reflect how sufficient each "child" query was for answering its corresponding "parent" query. Experts also gave a proportional value that reflected the amount of belief that they would normally expect to be available for answering each bottom-level query (otherwise referred to as a "leaf" hypothesis). All this was mapped out within the research framework and it was explained how weights could be attributed reflecting the influence that power and personality might have on recipient's receptivity, by taking account of known power and personality influences.

The remainder of this chapter describes how a deterministic two-agent model has been developed, and how this has been further developed into a dynamic two-agent model of receptivity that accounts for the confidence recipients will have in the sufficiency of submitted evidence. It is also suggested how this might be further developed into a multi-agent system and used to map out the brokering of evidence in risk-based regulation.

7.2. Presentation of the deterministic model

The previous chapter explains how a research framework was developed. Figure 34 illustrates the main components of the initial agent-based model. This is a two-agent model constructed within Microsoft Excel. It consisted of spreadsheet that contained a user interface. Sixteen spreadsheets drew upon values set within the user interface to calculate 10,000 runs of recipients' receptivity for 16 different scenarios. The mean value (with error bars representing standard deviation) representing recipients' receptivity calculated, for each scenario, was presented in a final spreadsheet.

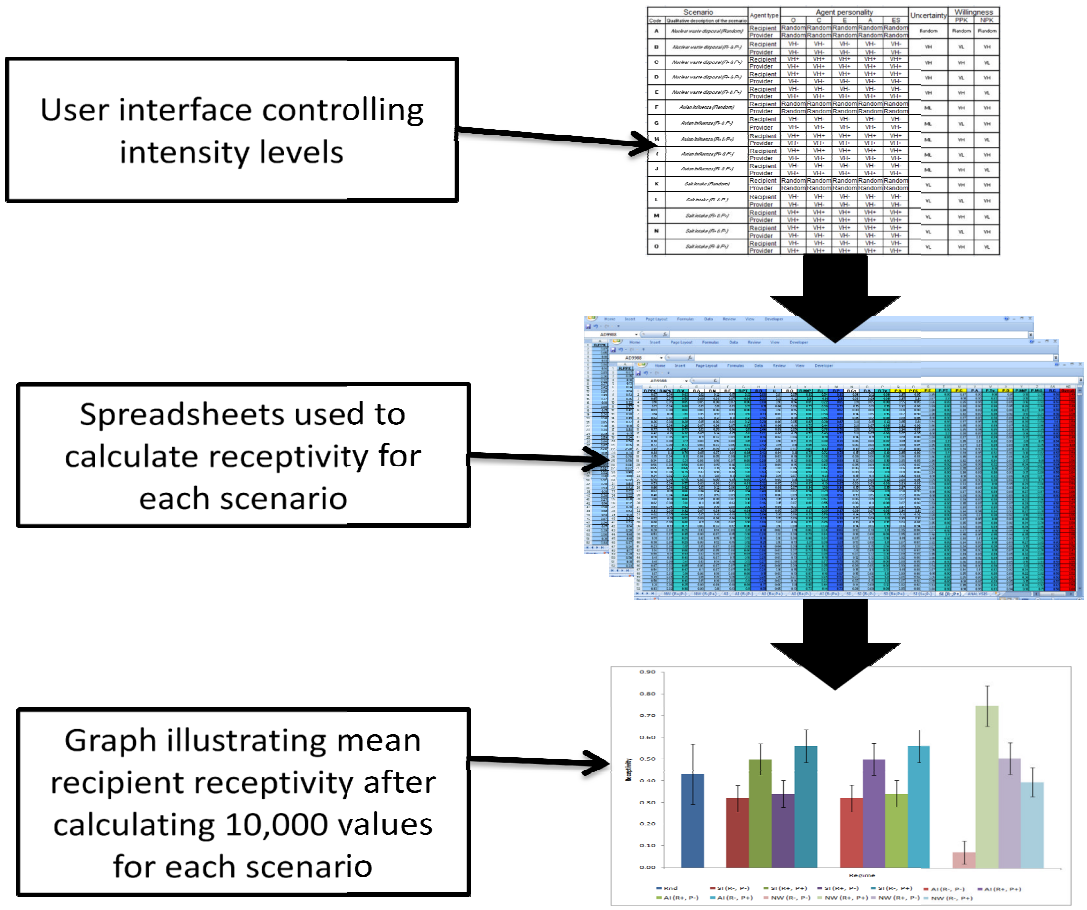


Figure 34: Connected account of the logic initial model

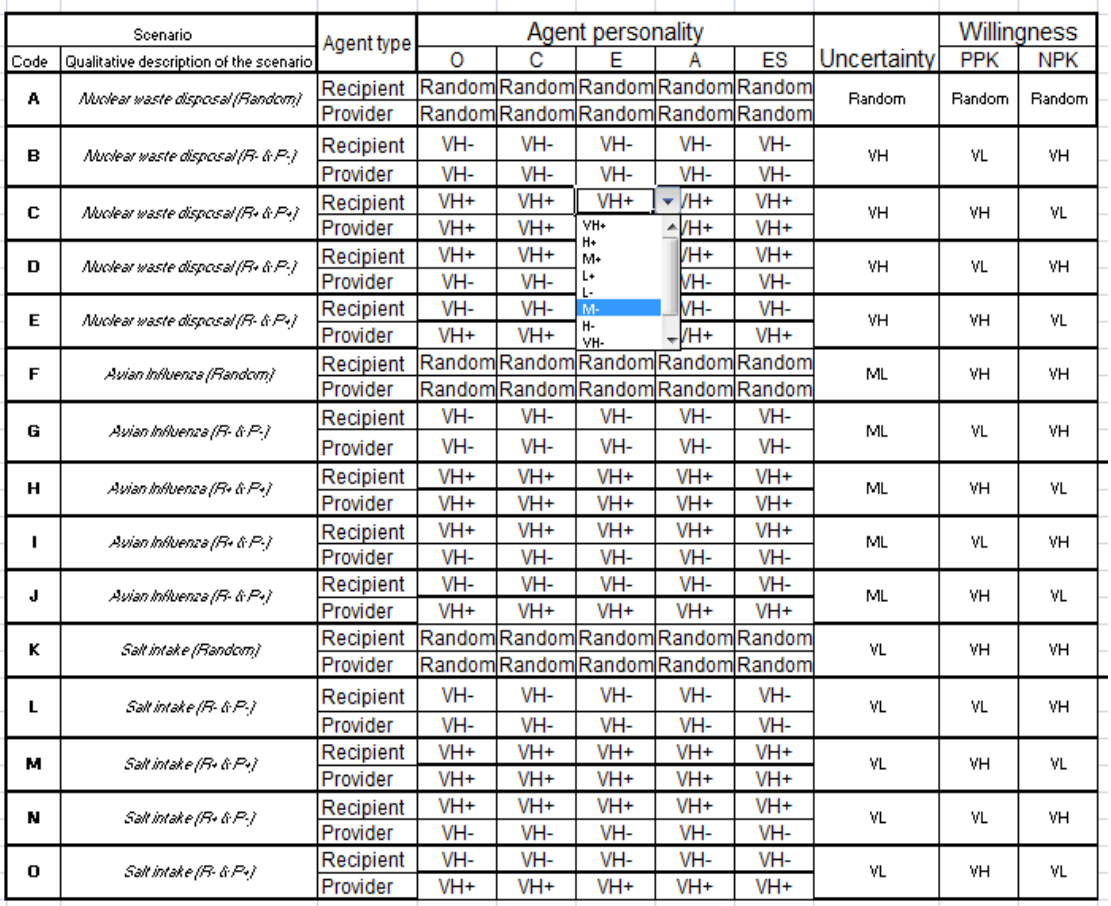
The user interface was intended to act as a means of "playing tunes" on the model, to allow the user to explore what range of conditions, affecting recipient's receptivity within the three case studies, the model was able to represent. The logic used to calculate recipient's receptivity is the same as that described in the review of known power and personality influences (set out in Chapter 2 and recently published in Davies et al., 2010). The method used to calculate receptivity was the same as that described within the development of the research framework (see Chapter 4), and as such it used the same parameters, illustrated here in Table 4.

Table 4: List of parameters used to calculate recipient's receptivity within each scenario

Code	Description of the scenario
R.PPK	Recipient's positive prior knowledge
R.NNPK	Recipient's negative prior knowledge
R.W	Recipient's willingness
R.A	Recipient's agreeableness
R.ES	Recipient's emotional stability
R.E	Recipient's extroversion
R.PT	Recipient's propensity to trust
R.R	Recipient's receptivity
U	Uncertainty
R.O	Recipient's openness to experience
R.MtP	Recipient's motivation to process evidence
R.L	Recipient's legitimate power
R.P	Receptivity in the processing stage
R.Cs	Recipient's conscientiousness
R.A	Recipient's agreeableness
R.Tw	Recipient's trustworthiness
P.A	Provider's agreeableness
P.ES	Provider's emotional stability
P.E	Provider's extroversion
P.PT	Provider's propensity to trust
P.C	Provider's conscientiousness
P.A	Provider's agreeableness
P.Tw	Provider's trustworthiness
P.O	Provider's openness
A.MtS	Agent's motivation to share
R.C	Recipient's conscientiousness
Overall	Overall receptivity

Recipient's receptivity was a product of taking the average influence of subordinate factors and propagating them up to form an overall receptivity value. This reflected recipient's receptivity across all three stages (i.e. the receiving, processing and passing-on stages).

Figure 35 is a screenshot of the user interface. Each scenario was given a code referring to the level of intensity that the scenario would reflect. Levels of intensity were presented as options within dropdown menus within each cell reflecting the relative intensity of a factor. For example, "H", "M" and "L" reflected a "high", "medium" and "low" intensity for that factor (e.g. representing the level of intensity of a personality trait, level of uncertainty or level of positive or negative prior knowledge). This was linked to the pertinent parameter values (using the "IF…THEN…" and "RANDBETWEEN" function in Excel), set out in the spreadsheet calculating recipient's receptivity for that particular scenario.



Scenario		Agent type	Agent personality					Uncertainty	Willingness	
Code	Qualitative description of the scenario		O	C	E	A	ES		PPK	NPK
A	*Nuclear waste disposal (Random)*	Recipient	Random	Random	Random	Random	Random	Random	Random	Random
		Provider	Random	Random	Random	Random	Random			
B	*Nuclear waste disposal (R- & P-)*	Recipient	VH-	VH-	VH-	VH-	VH-	VH	VL	VH
		Provider	VH-	VH-	VH-	VH-	VH-			
C	*Nuclear waste disposal (R+ & P+)*	Recipient	VH+	VH+	VH+	VH+	VH+	VH	VH	VL
		Provider	VH+	VH+		VH+	VH+			
D	*Nuclear waste disposal (R+ & P-)*	Recipient	VH+	VH+		VH+	VH+	VH	VL	VH
		Provider	VH-	VH-		VH-	VH-			
E	*Nuclear waste disposal (R- & P+)*	Recipient	VH-	VH-		VH-	VH-	VH	VH	VL
		Provider	VH+	VH+		VH+	VH+			
F	*Avian Influenza (Random)*	Recipient	Random	Random	Random	Random	Random	ML	VH	VH
		Provider	Random	Random	Random	Random	Random			
G	*Avian Influenza (R- & P-)*	Recipient	VH-	VH-	VH-	VH-	VH-	ML	VL	VH
		Provider	VH-	VH-	VH-	VH-	VH-			
H	*Avian Influenza (R+ & P+)*	Recipient	VH+	VH+	VH+	VH+	VH+	ML	VH	VL
		Provider	VH+	VH+	VH+	VH+	VH+			
I	*Avian Influenza (R+ & P-)*	Recipient	VH+	VH+	VH+	VH+	VH+	ML	VL	VH
		Provider	VH-	VH-	VH-	VH-	VH-			
J	*Avian Influenza (R- & P+)*	Recipient	VH-	VH-	VH-	VH-	VH-	ML	VH	VL
		Provider	VH+	VH+	VH+	VH+	VH+			
K	*Salt intake (Random)*	Recipient	Random	Random	Random	Random	Random	VL	VH	VH
		Provider	Random	Random	Random	Random	Random			
L	*Salt intake (R- & P-)*	Recipient	VH-	VH-	VH-	VH-	VH-	VL	VL	VH
		Provider	VH-	VH-	VH-	VH-	VH-			
M	*Salt intake (R+ & P+)*	Recipient	VH+	VH+	VH+	VH+	VH+	VL	VH	VL
		Provider	VH+	VH+	VH+	VH+	VH+			
N	*Salt intake (R+ & P-)*	Recipient	VH+	VH+	VH+	VH+	VH+	VL	VL	VH
		Provider	VH-	VH-	VH-	VH-	VH-			
O	*Salt intake (R- & P+)*	Recipient	VH-	VH-	VH-	VH-	VH-	VL	VH	VL
		Provider	VH+	VH+	VH+	VH+	VH+			

Figure 35: Screenshot of the user interface, illustrating how dropdown menus of permitted different levels of intensity to characterise each scenario.

Dropdown menus within the user interface took their respective intervals of intensity from descriptive tables contained within the same spreadsheet. These tables contained variable levels of intensity to characterise the influence of uncertainty (Figure 36), positive and prior knowledge (Figure 37) and personality (Figure 39). As an extra option, at the bottom of each dropdown menu there was the option to choose "Random". Selecting this option meant that random values (between 0 and 1) were assign to the factor being investigated. Options above the "Random" option reflected increasing level of intensity.

Six levels of intensity were used to characterise the influence of uncertainty. These permitted the user to constrain the parameters of the model to better represent the three case studies (salt intake, avian influenza and nuclear waste) that were characterised by a relatively low, medium and high level of decision uncertainty.

Levels of uncertainty:	
VH	0.825 to 0.99 % sure
H	0.66 to 0.8249 % sure
MH	0.495 to 0.659 % sure
ML	0.33 to 0.4949 % sure
L	0.165 to 0.329 % sure
VL	0 to 0.1649 % sure
Random	0 to 0.99

Figure 36: Levels of intensity available for characterising uncertainty

Levels of intensity reflecting the presence of positive and negative prior knowledge were intended to reflect the context of the brokering process in real-world risk-based regulation. Specifically, in the unstructured interviews a common theme that was referred to was the presence of good, bad and ugly operators. The good referred to those that knew what evidence the regulator wanted, had the resources to provide it and were willing to do so. The bad operators were referred to as those that were willing to provide the required evidence but failed to do so for reasons that related to the limited resources or understanding of what to was required. The ugly operators, on the other hand, were described as those that knew what to provide, had the resources and understanding but were unwilling to do so. Experts within the unstructured interviews explained that the result was the effect this had on their perception of the provider and their willingness to

engage in a trusting relationship with them affecting their perception of how sufficient they believed the submission of evidence to be. To capture this, Figure 37 illustrates the levels of intensity that could be assigned within the user interface. These reflected the likelihood that positive and negative prior knowledge would be attached to the submitted evidence, influencing recipient's receptivity toward the provider.

Levels of prior knowledge:	
VH	0.825 to 0.99 % chance of occuring
H	0.66 to 0.8249 % chance of occuring
MH	0.495 to 0.659 % chance of occuring
ML	0.33 to 0.4949 % chance of occuring
L	0.165 to 0.329 % chance of occuring
VL	0 to 0.1649 % chance of occuring
Random	0 to 0.99

Figure 37: Levels of intensity available for characterising recipient's positive and negative prior knowledge.

Psychologists that score personality generally agree that individuals that score 55 or higher are considered to have a strong dimension in the given factor. Conversely, those that score 45 or below are considered to have the opposite effect for the same factor. People that score between 45 and 55, on the other hand, fall within the standard deviation of the big five personality test. Accordingly, the most defensible option was to permit the model to generate a random number to reflect whether each personality trait would have a low (0 to 45), medium (45 to 55) or high (55 to 100) affect (Figure 38). This was coded as an option within the user interface. However, the option of selecting more refined levels of influence was also desirable to allow the influence specific values of personality were having on recipient's receptivity to be explored in greater detail. To

achieve this, the levels reflecting the intensity that personality traits might have was further refined into eight levels of intensity (Figure 39). This was not as defensible as the three levels of intensity but was considered to be justified to permit the sensitivity of results to be explored in greater detail.

Personality:	
H+	0.55 to 1
M+	0.45 to 0.55
L-	0 to 0.45
Random	0 to 1

Figure 38: Values effect, by generating a random number between 0 and 0.45, 0.45 and 0.55, and 0.55 and 1

Personality:	
VH+	0.85 to 0.95
H+	0.75 to 0.85
M+	0.65 to 0.75
L+	0.55 to 0.65
L-	0.35 to 0.45
M-	0.25 to 0.35
H-	0.15 to 0.25
VH-	0.5 to 0.15
Random	0 to 1

Figure 39: Levels of intensity available for characterising each personality trait

Aforementioned, each level of intensity reflected within the user interface was linked to a separate spreadsheet (as illustrated in Figure 34). Each column within these spreadsheets represented a parameter of the hierarchical model of recipient's receptivity

(Figure 40). These are the same parameters presented in the development of the research framework (Chapter 4). Moving from the left to right in Figure 40, values reflecting levels of intensity were propagated across to form an average recipient's receptivity for the receiving, processing and passing-on stage, and the average receptivity of these formed the overall recipient's receptivity (in the column to the far right of Figure 40). In total, each spreadsheet contained 10,000 rows. The mean recipient's receptivity of these 10,000 calculations (and the standard deviation) was then plotted on a graph illustrated in Figure 41.

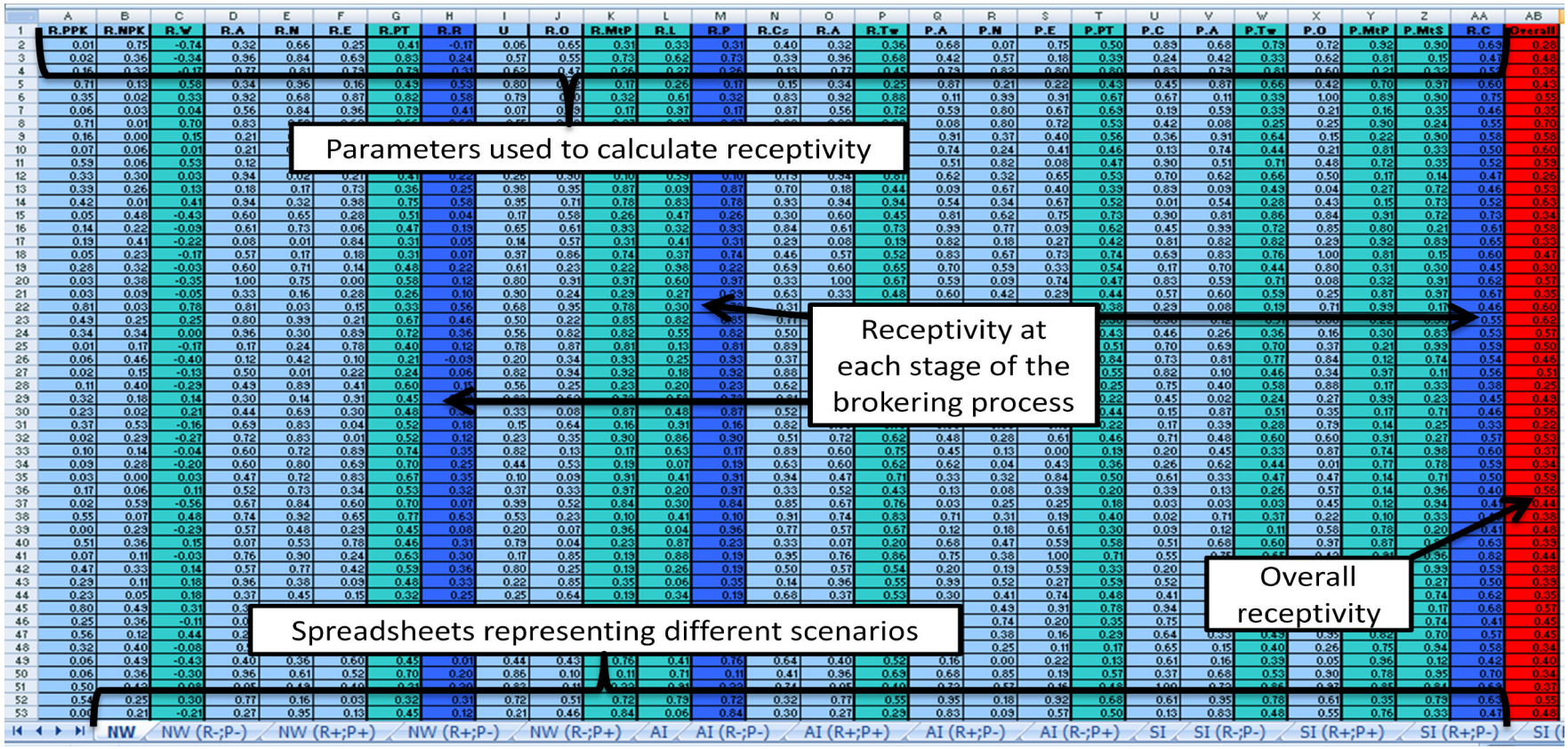


Figure 40: Example spreadsheet used within the initial model to characterise the nuclear waste disposal case study. Illustrating how each column represented a parameter used to calculate recipient's receptivity (contained in the last column on the right).

Figure 41 illustrates an output after running the model under situations that were structured toward the recipient and the provider either having a positive or negative impact on recipient's receptivity. Each bar in Figure 41 represents the mean of 10,000 recipient's receptivity values, calculated under the different scenarios. These scenarios were intended to represent the relative influence that the recipient's and provider's agent had on recipient's receptivity within the three case studies. Moving from the left to the right, the first bar represents a situation where intensity levels have been randomly set (between 0 and 1) each time receptivity was calculated. Each cluster (consisting of four bars) represents low, medium and high levels of uncertainty, reflecting the salt intake, avian influenza and nuclear waste case study, respectively. Then each bar, within each cluster, moving from the left to the right, represents recipient's receptivity being calculated under the following conditions:

- Both the recipient's and provider's agents are set to have a negative impact on recipient's receptivity;
- Both the recipient's and provider's agents are set to have a positive impact on recipient's receptivity;
- Recipient's and provider's agent is set to have a negative and positive impact on recipient's receptivity, respectively;
- Recipient's and provider's agent is set to have a positive and negative impact, respectively.

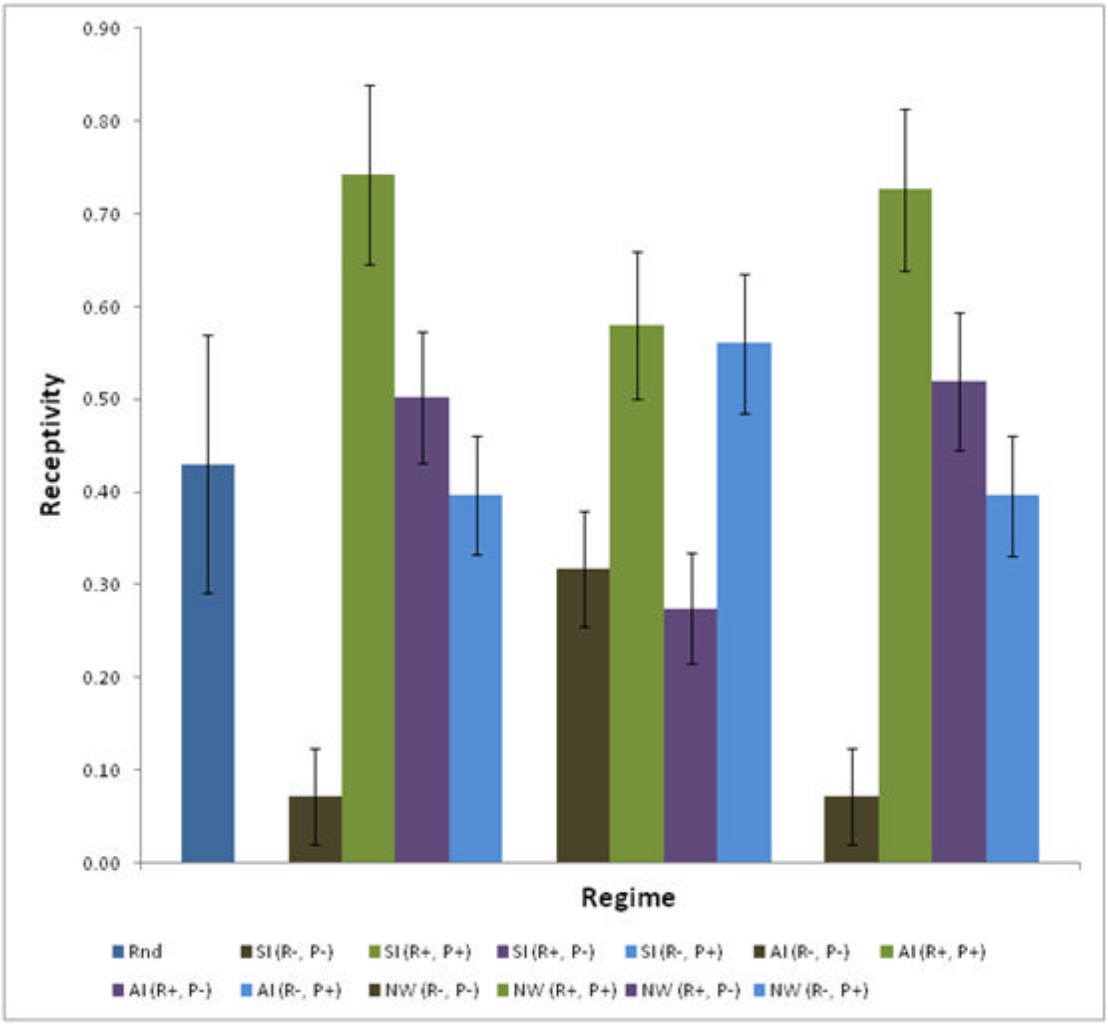


Figure 41: Mean recipient's receptivity after being calculated 10,000 times within 13 scenarios, with error bars representing standard deviation.

It can be seen from Figure 41 that there was a significant difference between the mean receptivity calculated within each parameter selected randomly between 0 and 1 and the mean receptivity in the first and second bar of the first and last cluster (representing the best and worst case for the salt intake and nuclear waste case study, respectively). This relationship is not seen in the avian influenza case study, in the middle cluster, because of the medium level of uncertainty characterising the avian influenza case study. Hence, under conditions of high and low uncertainty recipient's orientation toward being

receptive was greatest. Beyond this, the difference between the third and fourth bar, in the middle cluster, illustrate that the provider has a greater potential of impacting recipient's receptivity. This is because a provider that is positively positioned to imbue a recipient with receptivity is also going to be more likely to add toward the recipient's positive prior knowledge. Hence, the greater level of recipient's receptivity can therefore be explained by the recipient being more willing to engage in dialogue because they only have positive information about the provider.

This section described how the initial two-agent model was able to model the way experts described recipient's receptivity within the unstructured and semi-structured interviews. It uses known influences of power and personality (described in detail in Davies et al., 2010) and values reflecting extremes of personality and prior knowledge influences within the three case studies. The major drawback of this initial model, however, was its deterministic nature; it did not account for the dynamics of the brokering process. The following sections explain how this logic has been expanded to develop a dynamic model of recipient's receptivity and how this has been used to account for the influence those weights of evidence account, in combination with recipient's receptivity, for confidence building in risk-based regulation.

7.3. Presentation of the dynamic model of recipient's receptivity

The previous section explains how a deterministic two-agent model was developed to account for recipient's receptivity. This section explains how this was developed into a dynamic model. The dynamic model uses the same parameters to calculate recipient's

receptivity used within the deterministic model (Table 4). However, the dynamic model improves on the deterministic model by describing the two-way interaction (dialogue) that exists between the provider and the recipient. Experts in the unstructured and semi-structured interviews explained how recipients and providers come together to "negotiate" over the sufficiency of submitted evidence. Therefore, it was important that the agent-based model went beyond providing a "snap-shot" in time of average recipient's receptivity. It needed to account for not only the influence of recipient's receptivity, but also the influence of provider's receptivity.

Figure 42 illustrates the main components of this dynamic two-agent model. This is constructed within Microsoft Excel's Visual Basic Editor (see appendix). VBA code was used to update an "Agent environment" spreadsheet according to changes in agent's personal information and contextual issues derived from the "Scenario" spreadsheet before receptivity was calculated, stored in the "Data log" spreadsheet and used to generate graphs that illustrated recipient's receptivity over time.

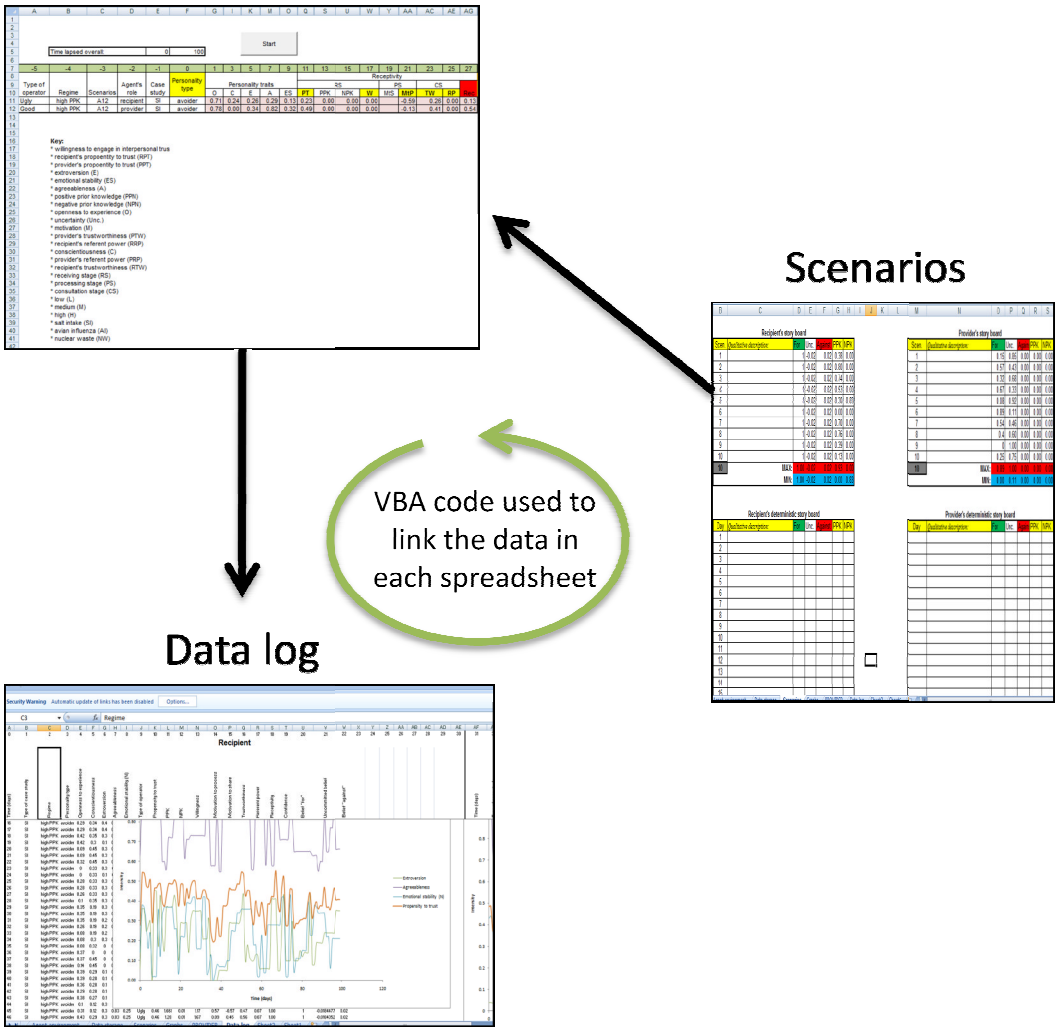


Figure 42: Connected account of the logical way the dynamic model of recipient's receptivity was modelled within Microsoft Excel using VBA code.

The obvious difference between the dynamic model of receptivity and the deterministic model is the account for the interaction between agents. Figure 43 is a screenshot of the main simulation routine written in VBA. The simulation is initiated by calling the "initialize_ model" subroutine. This is the point at which the recipient and provider agent are given values that are used to calculate receptivity. These parameters are the same as those used to calculate recipient's receptivity in the deterministic model. The exception being the addition of referent power.

```
Sub run()

Call initialize_model

'let recipints engage in dialogue according to the
'period in which their legitimate power permits them to
Do While [time_period] < [legitimate_power4]

    'RECIPIENT:
    Call update_recipients_personal_information
    Call populate_recipients_story_board
    Call update_recipients_details_with_appropriate_scenario
    Call calculate_recipients_confidence_and_adopted_belief
    Call log_recipients_data

    'PROVIDER:
    Call update_providers_personal_information
    Call populate_providers_story_board
    Call update_providers_details_with_appropriate_scenario
    Call Prepare_and_weight_evidence
    Call log_providers_data

    'TIME PASSED:
    [time_period] = [time_period] + 1

Loop

End Sub
```

Figure 43: Main simulation run setting out the logic of the dynamic model of recipient's receptivity

As explained in Chapter 3 referent power takes time to establish and refers to the holder of referent power being perceived as worthy of respect, admiration, affection causing other to want to gain their approval. Those it is imposed upon, therefore attribute referent power. To account for this, the model assumed that agents that have a high potential to obtain referent power do so at a rate that is quicker than those that have a low potential.

Scholars explain that referent power is positively associated with emotional stability and agreeableness (e.g. Karkoulian et al., 2009). As such, the model assumed that the average weight assigned to an agents emotional stability and agreeableness reflected their full potential of establishing referent power. If this average value was low, medium or high then the agent was considered to have a low, medium and high potential of gaining referent power. Because referent power is dependent on others recognition, an agent's potential of gaining it in the model was reflected as a short, medium and long period in which it would take the agents with variable potential to establish their full potential. This was accounted for by dividing the number of runs that the simulation had passed through by the short, medium or long period of time that it would take the agent to reach their full potential. Hence, reflecting that agents with a high potential will obtain a greater level of referent power in a quicker time compared to agents with a lower potential to establish referent power who will reach a relatively lower level and will take longer to obtain it. This was considered to be a reasonable assumption to make because referent power is dependent on the perceptions of others. Also, in the developed model this contributes toward receptivity. Therefore, an agent with a lower potential to establish referent power was less likely to have the attention of significant others, resulting in a lesser chance that their emotional stability and agreeableness would be recognised and attributed toward the agent as referent power.

Another addition to the dynamic model was the information contained within dropdown menus in the "Agent environment" spreadsheet that determined characteristics of the agent to be set. For example, this included permitting the selection of:

- Agent personality type;

- Type of operator;
- Regime; and
- Case study.

Agents could be assigned one of four personality types (negotiator, aggressor, submissive and avoider – following others that also used personality-based agents e.g. Nassiri-Mofakham et al., 2008/9; Santos et al., 2010). The big five personality traits (openness, conscientiousness, extroversion, agreeableness and neuroticism), referred to earlier in Chapter 3, were used in the model. The trait "emotional stability", referred to by scholars as the reverse of "neuroticism" (e.g. Costa and McCrae, 1991; Hills and Argyle, 2001), was used in the model for ease of modelling. This meant that values ranging from 0 to 1, assigned to any of the five personality traits would reflect low to high intensity, respectively. Then building on the existing knowledge of the four different personality types, each agent was assigned a low, medium or high value (0 – 0.45, 0.45 – 0.55 and 0.55 – 1 respectively). If the intensity of a trait relating to a personality type was not known then a level of intensity was selected from a uniform distribution and maintained within this band region for subsequent runs of the simulation. Table 5 illustrates the relative intensity levels that were assigned to each trait according to the personality type selected from the dropdown menu in the "Agent environment" spreadsheet.

Table 5: Relative levels of intensity (low, medium and high) assigned to each personality type, where "Random" refers to when the level of intensity were selected at random.

Personality type	Big five personality traits				
	O	C	E	A	N
Negotiator	Random	Medium	High	Medium	Medium
Aggressor	Random	High	High	Medium	Medium
Submissive	Random	Low	Low	Medium	Medium
Avoider	Random	Low	Low	Random	Low

The option to choose a specific type of operator was also made available in the "Agent environment". The type of operator related to the likelihood that submissions of evidence would come with connotations of positive and/or negative prior knowledge. The categories that were used to reflect this in the dropdown menu was referred to as a "good", "bad" and "ugly" type of operator. These reflected three levels of intensity (low, medium and high). The three types of operator were those that have been described in the description of the deterministic model. The "good" reflected a greater likelihood that submissions of evidence would come with connotation of negative prior knowledge and a lesser likelihood that submissions would come with negative prior knowledge. The "bad" reflected an equal chance of the evidence having connotations of negative and positive prior knowledge. The "ugly", on the hand, was in contradiction to the "good" type of operator (Table 6).

Table 6: Levels of intensity reflecting likelihood that submissions of evidence will imbue the recipient with positive or negative prior knowledge, based on the type of provider submitting the evidence.

Type of provider	Recipient's prior knowledge	
	Positive	Negative
Good	High	Low
Bad	Medium	Medium
Ugly	Low	High

Regime was included to reflect the recipient's discretion to choose between a number of lines of evidence. In total, eight regimes were made available to the recipient's agent. These included the option to always choose the evidence that was known to be characterised by high or low uncertainty or positive and negative prior knowledge. Beyond this, the model gave the option to choose evidence randomly or deterministically. The latter option permitted the model to explore how different types of recipients and providers would come to different conclusions regarding the confidence that they have in the same evidence being submitted in a predetermined order. This gave the model an extra dimension and the ability to explore the influence a greater number of scenarios that are known to characterise the brokering process.

The dropdown menu in the "Agent spreadsheet" relating to the column titled Case Study was equal to that of choosing intensity levels in the deterministic model. The only difference was the dynamic model incorporated three levels rather than six. Relating

these to the case studies being investigated, these were referred to as “SI” (salt intake), “AI” (avian influenza), “NW” (nuclear waste) and “Random”.

After “initializing” the model, the directional flow of evidence, characterising the brokering process, was captured in a number of subroutines (Figure 43). These were called upon in a logical order to mimic the sequence of events that experts described as characterising the brokering of evidence. This bouncing back and forth of evidence between the recipient and provider was permitted to continue until the “Do While / Loop” function in VBA determined that the number of permitted simulation runs had been carried out. Hence, the model assumed that one submission of evidence is made per day. The number of days of consultation is set by the value of the recipient’s legitimate power, which decreases, by a value of one with each run. Each simulation run represents one day of consultation.

The logic characterising the sequence in which subroutines were called upon (Figure 43) during the consultation period is illustrated in Figure 44. The model dictated that the brokering process started with the provider making a claim that they have complete confidence in the sufficiency of the evidence they are submitting (i.e. represented as a value of one).

After receiving the evidence the agent-based model;

- updated the agent’s personal information;
- populated the story boards with scenarios;

- selected a scenario, abstracted information characterising the new belief and positive and negative prior knowledge, and recalculated agent's receptivity;
- logged data relating to each of the values calculated for each of the parameters and the calculated measure of receptivity in the "Data log" spreadsheet.

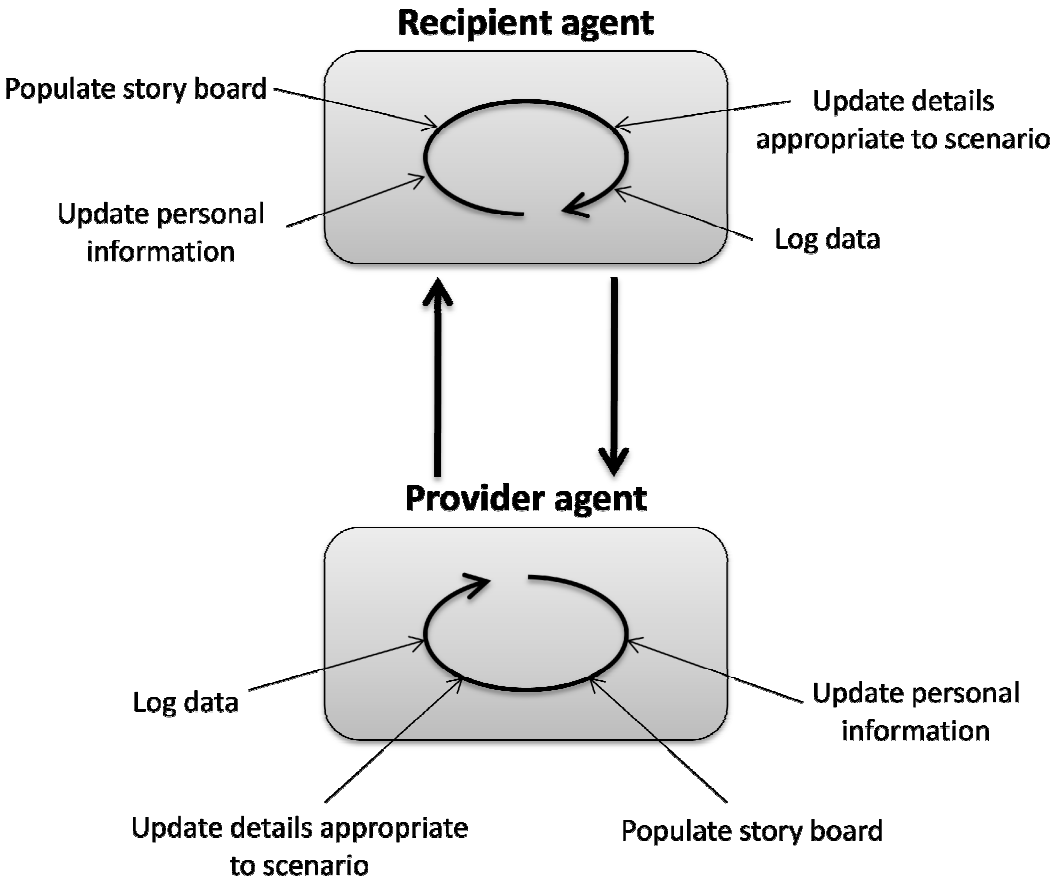


Figure 44: Process describing the logic supporting the process by which the recipient and provider engaged in dialogue over the sufficiency of submitted evidence.

After the evidence was received, the first task was to update the recipient's personal information (Figure 45). This was done to reflect the fact that personality is not a

constant measure over time, nor will it equally influence human behaviour across different decision context (e.g. Costa and Mcrae, 1991).

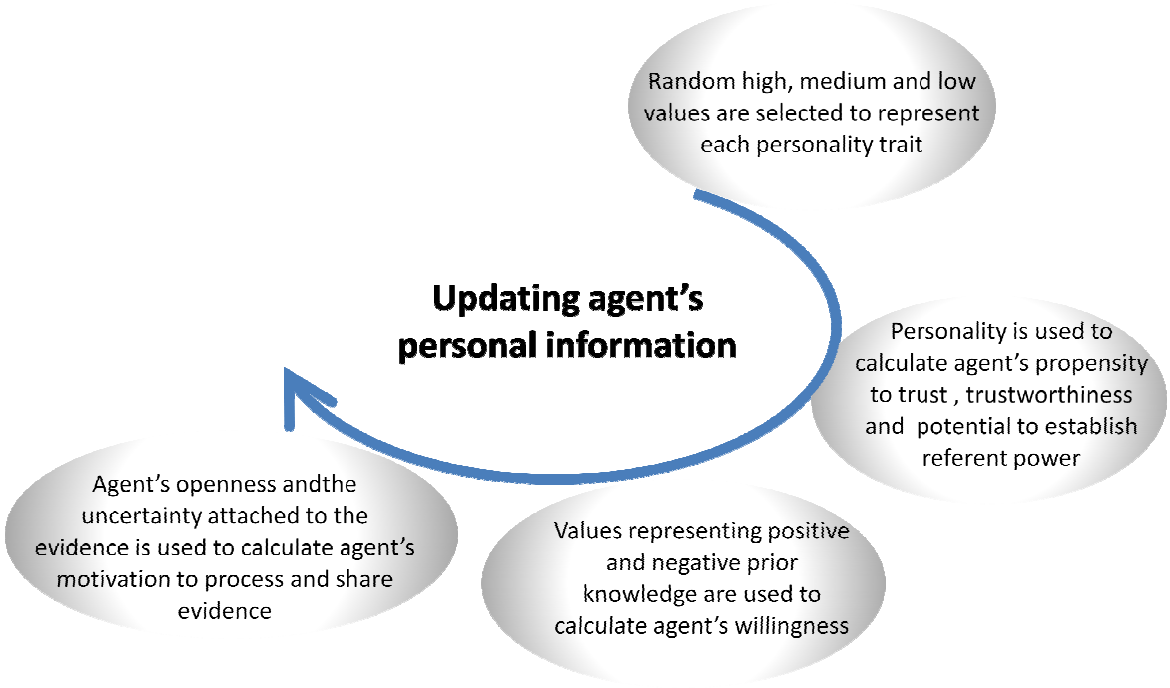


Figure 45: Logic sequence of events explaining how the agent's personal information was updated.

Updating personal information consisted of generating a new random weight to reflect the low, medium or high intensity level assigned to each of the agent's personality trait in the "initialize_ model" subroutine. Propensity to trust, trustworthiness, motivation to process evidence, and willingness, were all calculated as they were in the deterministic model, and the referent power was calculated as it was explained earlier in this section where it is described how the model was "initialized". Then to reflect the fact that agents were now engaged in dialogue, their motivation to share knowledge was also calculated.

Motivation to share knowledge is explained as a measure determined by whether agents are equally motivated to process the evidence (e.g. Whittom and Roy, 2009). Chapter 3 explains how motivation to process information is a function of the agent's openness to experience and the level of uncertainty characterising the submission of evidence (e.g. Hodson and Sorrentino, 1999). High or low values of both result in a high motivation to process the evidence systematically and carefully. Sorrentino et al. (2003) explained that those that are uncertainty orientated are fuelled by pride and ambition compelled to process uncertainty at any cost. Conversely, those that are certainty orientated are said to have a fear of failure, avoiding uncertainty at all costs. This difference in motivation toward processing information has been noted elsewhere and demonstrated that complementary measures of openness are most conducive to knowledge sharing, suggesting that underconditions of high or low uncertainty, dyads that are both uncertainty orientated or certainty orientated, respectively, will be more interested in pursuing their own agenda than sharing knowledge. Hence, agents that both have a high or low motivation to process evidence are said to be unmotivated to share knowledge. To reflect this, the model assigns a high value between 0.5 and 1 to agents that are motivated to share knowledge and a low value between 0 and 0.5 to those that were unmotivated to share knowledge.

After updating the agent's personal information, the next logical step in the simulation was to populate the agent's storyboard. Each agent had two types of storyboard. One existed to permit the model to generate the result of 10 lines of evidence for each submission. Each of these submissions had a random value between 0 and 1

representing belief for and against and weights reflecting connotations of positive and negative prior knowledge, attached to the evidence (Figure 46). The level of the latter was set by the type of provider for the recipient, or the type of coercion or reward power the recipient chose to exercise, for the provider. The other storyboard existed to let the agent address a series of submissions in a predetermined order.

Scen.	*Qualitative description*	For	Unc.	Again	PPK	NPK
1		0.15	0.85	0.00	0.00	0.00
2		0.57	0.43	0.00	0.00	0.00
3		0.32	0.68	0.00	0.00	0.00
4		0.67	0.33	0.00	0.00	0.00
5		0.08	0.92	0.00	0.00	0.00
6		0.89	0.11	0.00	0.00	0.00
7		0.54	0.46	0.00	0.00	0.00
8		0.4	0.60	0.00	0.00	0.00
9		0	1.00	0.00	0.00	0.00
10		0.25	0.75	0.00	0.00	0.00
10	**MAX:**	0.89	1.00	0.00	0.00	0.00
	MIN:	0.00	0.11	0.00	0.00	0.00

Figure 46: Screenshot of an agent's storyboard, in which values representing belief for, against and uncommitted and levels of positive and negative knowledge were randomly generated for ten lines of evidence.

After populating the agent's storyboard (Figure 46), one source of evidence was selected (according to the agent's preset regime, explained earlier in this section). Then using "Offsets" in VBA the information relating to beliefs (for, against and uncommitted) and connotations of positive and negative prior knowledge were

abstracted and aggregated with the agent's pre-existing information contained in the "Agent environment" spreadsheet. This was carried out by using the concept of dependency (explained in the development of the research framework in Chapter 4). This was necessary to account for the insight captured in the interviews that explained that new evidence is rarely 100% new. Also, connotations of positive and negative knowledge attached to it are rarely told just once to the recipient during the brokering of evidence.

This permitted the model to ensure that the agent acted in a rational manner (as an intelligent customer, so to speak), with the capacity to realise when they were being told something they already knew and therefore avoided double counting the old evidence.

The last thing for the recipient's agent to do was to calculate how receptive they were given their updated personal information and their knowledge of the measure of decision uncertainty and positive and negative knowledge characterising the submission of evidence.

In the deterministic model (and the development of the research framework set out in Chapter 4), overall receptivity was calculated by taking the average values of supporting factors within each stage. The same logic was applied to the dynamic model of receptivity.

Once recipient's receptivity was calculated, agent's updated information contained within the "Agent environment" spreadsheet was stored in the "Data log" spreadsheet,

before the evidence was bounced back to the provider with the updated measures of belief and any connotations of positive or negative knowledge attached to it, reflecting a recipient's ability and decision to enforce reward or coercive power. Then the process explained above for the recipient (regarding the process followed to update personal information, populating the pertinent storyboard, updating the agent with the details relating to the appropriate scenario and logging of data) is the same process that the provider follows to determine their receptivity.

The dynamic model of receptivity was considered successful in the sense that it modelled how the recipient's and provider's receptivity might change over the period of engaging in dialogue, based on the interplay of known power and personality influences. However, it was limited in its ability to account for the provider's ability to have any sustained influence on the recipient accepting that the evidence being submitted was actually sufficient for answering their query. To address this, the logic set out in the dynamic model of recipient's receptivity was built upon to develop a dynamic model of confidence building. How this was developed has been explained in the following section.

7.4. Presentation of the dynamic model of confidence building

Building on the logic set out in the dynamic model of receptivity, this section explains how measures of confidence were incorporated. Experts in the unstructured and semi-structured interviews explained that the brokering of evidence was characterised by providers trying to convince recipients that their submissions of evidence were

sufficient for answering their query. However, this was not reflected in the dynamic model of receptivity. The dynamic model of receptivity captured the interactive nature of the brokering process, characterised by providers making multiple submissions. However, as it stood, it failed to show how the provider could make any sustained progress toward imbuing the recipients with a lasting measure of confidence. This section explains how the confidence building process has been modelled into the dynamic model of receptivity.

Figure 47 illustrates the logic characterising the processes of confidence building in risk-based regulation. This is founded on insights provided by experts in the unstructured and semi-structured interviews. Assuming that the brokering process is initiated by the provider making a submission of evidence, recipients assessed the evidence and asked whether it imbued them with confidence. If it did, this measure of confidence was recorded and accounted for in the recipient's measure of receptivity toward the provider. Assuming that the recipient had the legitimate power and the desire to engage in dialogue, they bounced the evidence back to the provider with their measure of confidence attached to it.

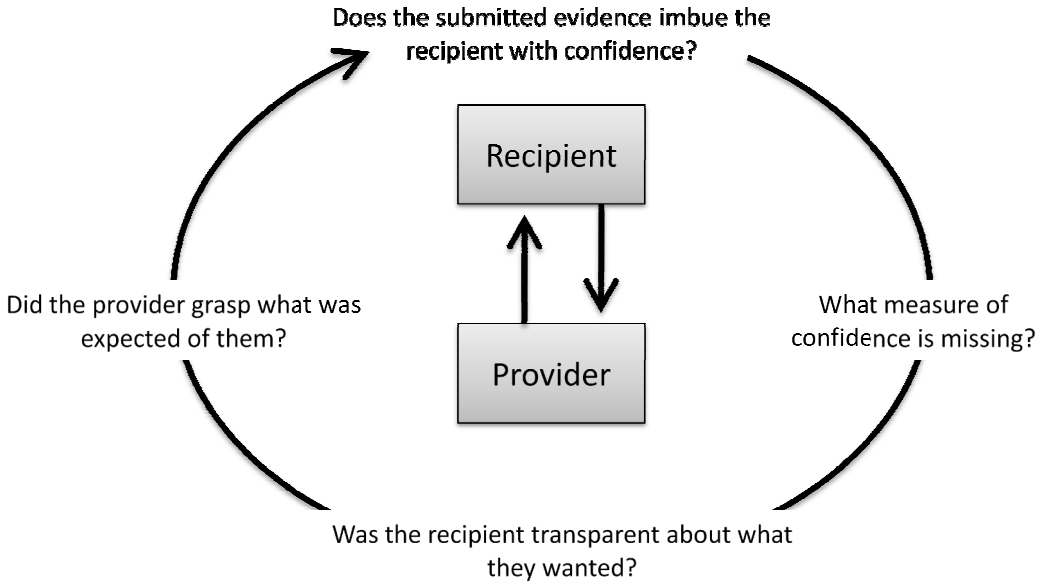


Figure 47: Logic that describes the confidence building exercise. The agent's questions asked sequentially in a clockwise order, starting with the provider.

To account for the two-agent model the recipient generated random weights (between 0 and 1) and assigned these to each type of evidence being brokered. This occurred in the "initilize_model" sub routine. Figure 48 presents the six types of evidence that were used to weight each submission of evidence. These were the same six types of evidence used in the semi-structured interviews.

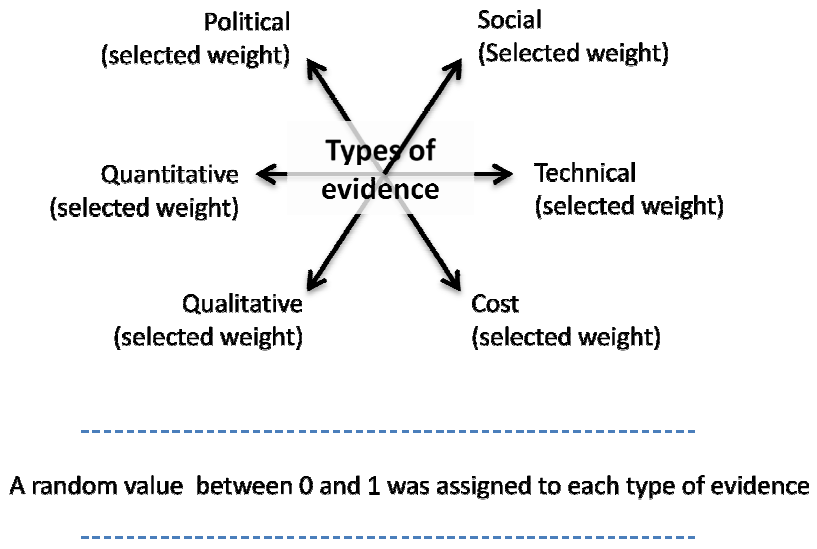


Figure 48: Method used to calculate the relative weight that the recipient assigned to each type of evidence being brokered.

At this point, the provider checked to see how transparent the recipient was regarding the type of evidence they wanted to receive. The recipient's receptivity was used as measure of how transparent the recipient was regarding what type evidence they wanted. This value was then multiplied against the provider's receptivity. The provider's receptivity gave an indication of the likelihood that the provider would grasp what the recipient was asking them to submit. The resulting value fell between a maximum and minimum value. The number range that fell between this maximum and minimum value was used as a scale on which to determine the likelihood that recipients would know what type of evidence the recipient wanted to receive.

A provider with a low, medium or high chance of knowing what the recipient wanted was reflected by generating a random number for each type of evidence (between 0 & 0.99, 0 & 0.59 and 0 & 0.29 respectively). This constellation of weights was submitted

to the recipient with the evidence. Then the recipient, assessing how well the submitted evidenced addressed their concerns (the type of evidence they were looking for), multiplied these randomly generated numbers against the weight that they had assigned to the same type of evidence.

Figure 49 illustrates the table used with the "Agent environment" spreadsheet to calculate recipient's confidence. The column to the far left represent a number of lines of evidence presented to the recipient. To the right of this column are six columns representing each of the types of evidence used to characterise each line of evidence. These are the same as those used in the semi-structured interviews and described in Chapter 6. The last three columns, moving left to right, represent the "original total", the "current total" and "current confidence". At the bottom of the table there is the sum of the "original overall total", "current overall total" and the "overall confidence".

	Types of evidence								
No.	Political	Social	Cost	Technichal	Qual.	Quan.	Original total	Current total	Current confidence
1	0.00	0.00	0.00	0.00	0.00	0.00	2.75	0.00	100
2	0.00	0.00	0.00	-	0.00	0.00	3.02	0.00	100
3	0.00	0.00	0.00	0.00	0.00	0.00	4.03	0.00	100
4	0.00	0.00	0.00	0.00	0.00	0.00	3.66	0.00	100
5	0.00	0.00	0.00	0.00	0.00	0.00	1.43	0.00	100
6	0.00	0.00	0.00	0.00	0.00	0.00	1.81	0.00	100
7	0.00	0.00	0.00	0.00	0.00	0.00	3.29	0.00	100
8	0.00	0.00	0.00	0.00	0.00	0.00	2.48	0.00	100
9	0.00	0.00	0.00	0.00	0.00	0.00	2.27	0.00	100
10	0.12	0.02	0.47	0.12	0.05	0.48	3.23	1.24	61
						Original overall total	27.97		
							Current overall total	1.25	
								Overall confidence	95.55

Figure 49: Table used in the "Agent environment" spreadsheet to calculate recipient's receptivity.

The weights submitted by the provider (relating to each type of evidence) were multiplied against the weight that the recipient had assigned to that type of evidence for that particular line of evidence. If the provider generated a value of "0" to any of the types of evidence then multiplying this against the recipient's weight resulted in a value of "0". Hence, the provider was considered to have fully addressed that particular type of evidence giving the recipient complete confidence in the sufficiency of that type of evidence being submitted. Then the total of the recipient's weights across one line of evidence was recalculated and referred to as the "current total" in Figure 49. This was divided by the "original total" and the product was subtracted from the value of one to reflect how confident the recipients were regarding the sufficiency of the submitted evidence. Confidence grew as the different types of evidence were addressed, until a value of 0 was all that was remaining next to each type of evidence. This was the case because any value greater than "0" being subtracted from the value of "1" results in a value less than "1" reflecting less than 100% confidence in the sufficiency of the submitted evidence.

Then to reflect how confidence might build over a period of time this same logic was applied to the total measure of weights being addressed at the bottom of the table illustrated in Figure 49. If the provider was not able to generate a value of "0" next to each type of evidence, through the course of the simulation, this was taken to mean that the provider was unable to address all of the recipient's concerns, restricting the recipient from gaining full confidence in the sufficiency of the submitted evidence.

7.5. Chapter summary and conclusions

This chapter has outlined the development of a two-agent model for risk-based regulation. This model encompasses all the factors and element that have been sustained through the research. It has evolved from being a deterministic model to a dynamic model of receptivity that can account for an agent's confidence in the sufficiency of submitted evidence.

The objective of developing the two-agent model was to compare the influence participants have on the brokering of evidence in risk-based regulation. Comparing the impact different entities have on a common phenomenon requires measuring their influence on a common scale. Experts in the unstructured and semi-structured interviews each explained that the brokering process consisted of recipients and providers of evidence that must pass through a receiving, processing and passing-on stage. Comparing the influence participants have on this process, the two-agent model incorporated influences of personality and power to form a measure of confidence and receptivity.

The model assumed that agent receptivity is a function of an agent's propensity to trust, trustworthiness, willingness, perceptions of others having referent power, motivation to process evidence, motivation to share knowledge and confidence in the sufficiency of the submitted evidence. Chapter 3 and 6 explicitly explain how others support the use of these parameters for calculating agent's receptivity.

The developed model considered receptivity synonymous with transparency to account for the extent to which agents could be considered transparent. Scholars explain that receptivity facilitates knowledge sharing (Deng, 2007; Wang et al., 2008; 2009). Specifically, Kearney (2007) explains that the opposite of receptivity is resistance. In line with this, the model assumed that a reduced agent's receptivity results in an equal increase in resistance.

Recipient's receptivity was used in the model as a measure of transparency, permitting the model to determine how open the agent would be with regards to the "type" of evidence that would imbue them with confidence (e.g. social, political, technical, costly, qualitative and quantitative). In the agent-based model, recipient's agents ranged from being transparent to opaque in nature. It assumed that transparent agents openly told providers the value they placed on different types of information characterising scientific evidence. Conversely, opaque agents did not disclose these relative values to the provider. In the extreme case, if a recipient was highly opaque then the provider had to guess how to frame their evidence to imbue the recipient with confidence. This approach permitted the model to explore how different agents could cope to fulfil the different role regulators (acting as recipients) play in each case study.

In the nuclear waste case study, the expert explained that they were not in a position to "hold the operators' hand", so to speak; it was not desirable that they would tell the operator exactly what type of information they should submit. This was in contrast to the salt intake and the avian influenza case study. In the latter, it was vital but in some respects, it was more a question of how transparent the food manufacturers (as the

operator) were about the types of evidence they value. Getting this right permitted the food standards agency (as the policy maker) to convince the operator that there was just cause why they should comply with voluntary standards.

In the developed model, providers of evidence had the task of trying to imbue recipients with confidence through submissions of evidence to fit with how a recipient valued different types of evidence. However, synonymous with trading agents in a financial market, recipients and providers behave differently under different conditions.

Accounting for the influence that provider's receptivity had was an important milestone in the development of the two-agent model. It assumed the provider's receptivity determined the extent to which the agent was able to grasp what the recipient was telling them. Conclusively, experts in the unstructured and the semi-structured interviews explained how providers of evidence played an important role in the judgements made regarding the sufficiency of submitted evidence. The expert within the nuclear waste case study gave a prime example. On more than one occasion, the operator had been told to submit a qualitative account of how risk ranging 100,000 years into the future would be managed. The operator, however, was "unreceptive" and did not grasp what the regulator (recipient) was asking of them. Hence, providers of evidence have the chance of missing opportunities to imbue the recipient with greater confidence (and receptivity) by failing to give them what they asked for. This has been captured within the model of confidence building by accounting for provider's receptivity and the influence this has on their ability to grasp what is being asked of them.

Combining knowledge of recipient's and provider's receptivity permitted the model to determine the likelihood that the provider would know what type of evidence would imbue recipients with confidence. In the model, it was assumed that providers, faced with an opaque recipient, still had a chance of "guessing" what type of evidence would imbue the recipient with confidence. Highly receptive recipients permitted the provider to view specific weights and gave them a greater chance of addressing each type of evidence; hence, openly divulging how recipients valued evidence. Combining high levels of recipient's and provider's receptivity gave the providing agent the best chance of knowing what type of evidence would imbue the recipient with confidence.

In the model, the recipient's agent gains confidence when the correct type of evidence is submitted. Evidence is checked by the recipient and if it is of the correct type it is crossed of the shopping list, so to speak, and attributed toward confidence. When each type of evidence has been addressed in full, the recipient is assumed to have complete confidence in the sufficiency of the submitted evidence.

The developed two-agent model has shown how it was possible to calculate a weight reflecting agent's confidence in the sufficiency of evidence. This two-agent model could now be used to inform/support the developed research framework. It is possible to account for the influence power structure and personality may have on the weight of a particular line of evidence by generating a weight reflecting recipient's confidence in the sufficiency of evidence and multiplying this against the sufficiency weight within the research framework (Chapter 4).

Having developed the two-agent model that can account for an agent's confidence in the sufficiency of submitted evidence, it is now possible to develop this further into a fully-fledged multi-agent system. Such a model could draw on aspects of existing agent-based models that model agents as buyers and sellers (e.g. Mizuta and Steiglitz, 2000; Kim, 2007; Nassiri-Mofakham et al., 2008 & 2009). Agents wishing to sell a commodity would have to determine whether bids for the commodity are acceptable. Eventually, when the buyer makes an acceptable bid the seller agent would exchanges the commodity for a specified currency. This logic where a buyer and seller agents negotiate/barter over the cost of a commodity is synonymous to the logic explaining how agents engage in the brokering of scientific evidence and knowledge. Agents would come together to negotiate over the sufficiency of scientific evidence being submitted. From this perspective, the recipient's agent would be the seller and the commodity they have to sell is sufficiency. The agent providing the scientific evidence and knowledge, on the other hand, would be the buyer and the currency they want to exchange for this sufficiency is confidence, in the form of scientific evidence. In this context, confidence would be multi-factorial and contingent on a recipient's receptivity and the quality of evidence being submitted.

The two-agent model presented in this chapter is intended to be used as an exploratory tool. These assumptions set out in this chapter were believed to be necessary for modelling the influence power and personality has on the brokering of evidence in risk-based regulation. The output from the model development has been presented in the following chapter as a proof of concept.

This page is intentionally blank

Chapter 8

PROOF OF CONCEPT

This thesis has sought to provide a richer description of the brokering of scientific evidence in risk-based regulation by focusing on social science aspects of decision-making. This has been addressed through the development of a two-agent model of receptivity. Chapter 7 set out how this two-agent model was developed from a deterministic to a dynamic model of receptivity that could inform the confidence recipients have in the sufficiency of submitted evidence. This chapter sets out a proof of concept. It demonstrates how decisions regarding the sufficiency of evidence are informed by changes to system parameters. Moreover, it demonstrates the extent to which the automated decision making system is able to capture the confidence-building exercise observed in the three real-world case studies.

8.1. Proof of concept study

Scholars stress the importance of demonstrating rigour to give research value (e.g. Morse et al., 2002). To this end, a deterministic sensitivity analysis was carried out on the developed two-agent model to demonstrate its ability to account for influences of power and personality. This has involved measuring the strength of relations between input and output variables. The remainder of this section provides proof that the developed two-agent model was able to simulate the influence different personality types, positive and negative prior knowledge, and decision uncertainty had on agent

receptivity. Moreover, it is demonstrated how this was used to simulate confidence building.

Chapter 7 presented the four personality types being investigated. These included the negotiator, aggressor, submissive and avoider personality type. Intensity levels assigned to support personality traits had an independent effect on agent's propensity to trust and trustworthiness. Figure 50 also illustrates that the avoider type of personality, with a low measure of extroversion produced the least propensity to trust.

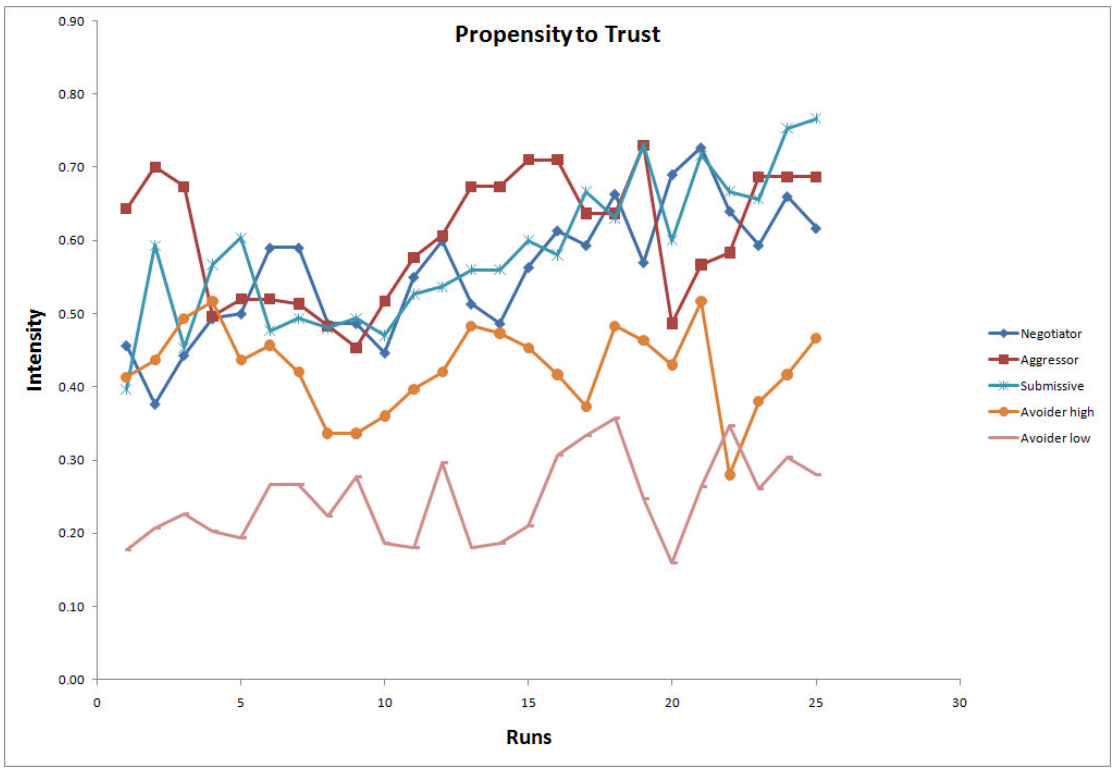


Figure 50: Propensity to trust calculated using the negotiator, aggressor, submissive and avoider type of personality. "Avoider high" and "Avoider low" refer to the avoider type personality with high and low measures of extroversion.

Figure 51 illustrates agent's relative measures of trustworthiness calculated for each of the four personality types included in the two-agent model. Aforementioned (in Chapter 7) the personality types did not specify a specific level of intensity for each trait. To account for this, the avoider personality type is shown twice in Figure 51, with a high and a low measure of agreeableness. This figure illustrates that the avoider type of personality with a low measure of agreeableness had the least capacity to establish trustworthiness.

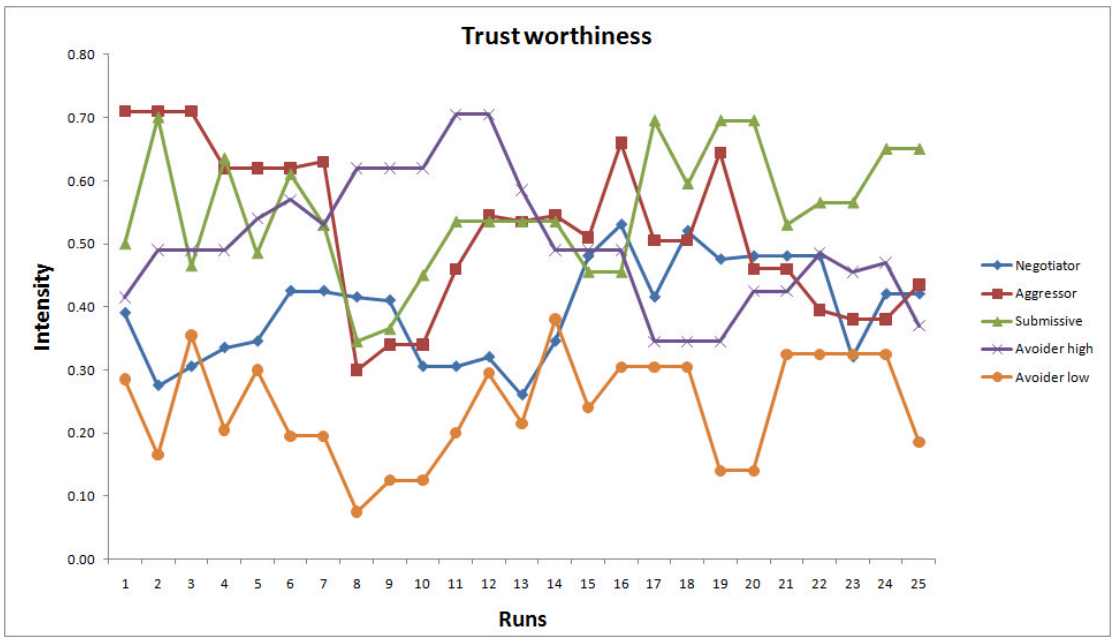


Figure 51: Trustworthiness calculated using the negotiator, aggressor, submissive and avoider type of personality. "Avoider high" and "Avoider low" refer to the avoider type personality with high and low measures of agreeableness.

The intensity level assigned to an agent's referent power was dependent on the agent's personality and the time the agent was permitted to engage in dialogue. High average

intensity of agreeableness and emotional stability was used to represent an agent's high potential to establish referent power. It can be seen that agent's with the submissive type of personality that had a low intensity value of agreeableness and emotional stability had the lowest potential to establish referent power and took longer to establish it.

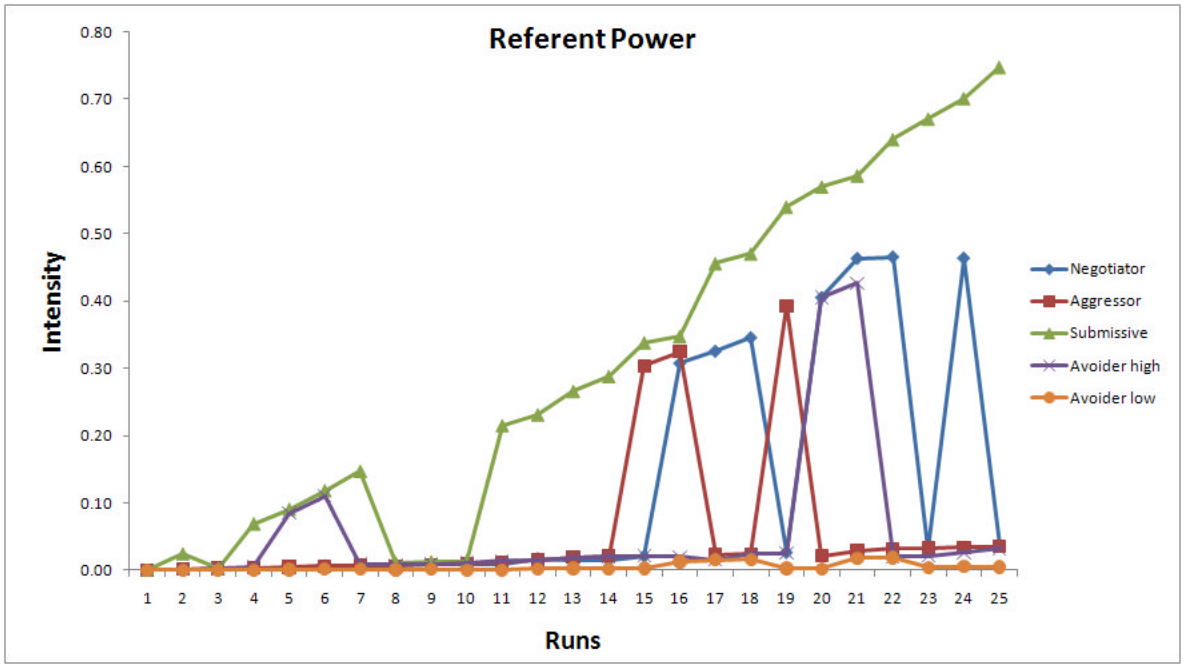


Figure 52: Referent power calculated for the four different personality types

High openness to experience and uncertainty or low measures of both, resulted in agents being highly motivated to process evidence systematically and carefully. All of the personality types included in the model had a random chance of having a low, medium or high openness to experience. Figures 53 to 55 illustrate the average intensity generated over 1000 runs representing the best and worst circumstances e.g. when agents with low and high openness to experience in the presence of low and high uncertainty, to show extremes of motivation incorporated in the two-agent model.

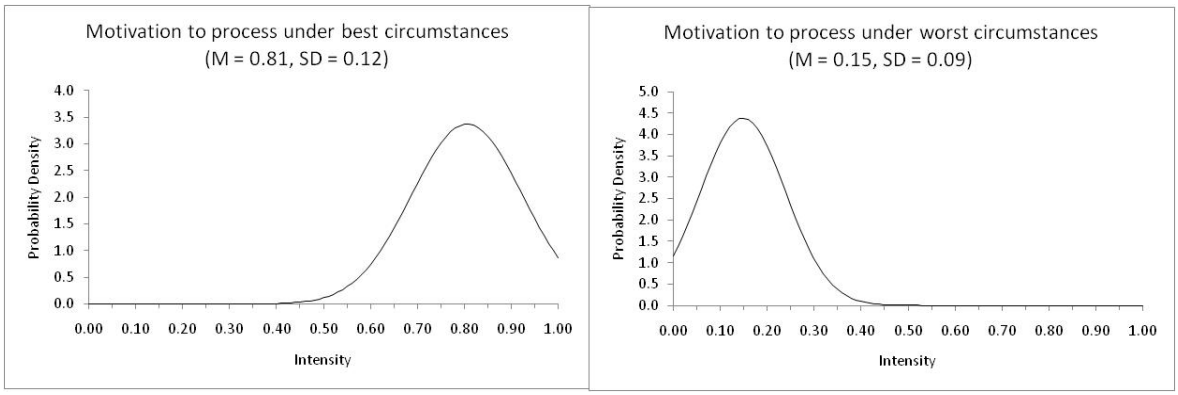


Figure 53: Motivation to process evidence calculated for agents with low and high measures of openness in the presence of low and high uncertainty.

Agent's motivation to share knowledge was dependent on how each agent was motivated to process the evidence. Figure 53 illustrated the relative intensity that represent agents with a low and high motivation to share knowledge. In line with insights set out in the literature review (in Chapter 3), if the provider and recipient were unequally motivated to process the evidence then they were considered to be highly motivated to share knowledge. Conversely, providers and recipients that were equally motivated to process evidence were considered to have a low motivation to share knowledge as shown in Figure 54.

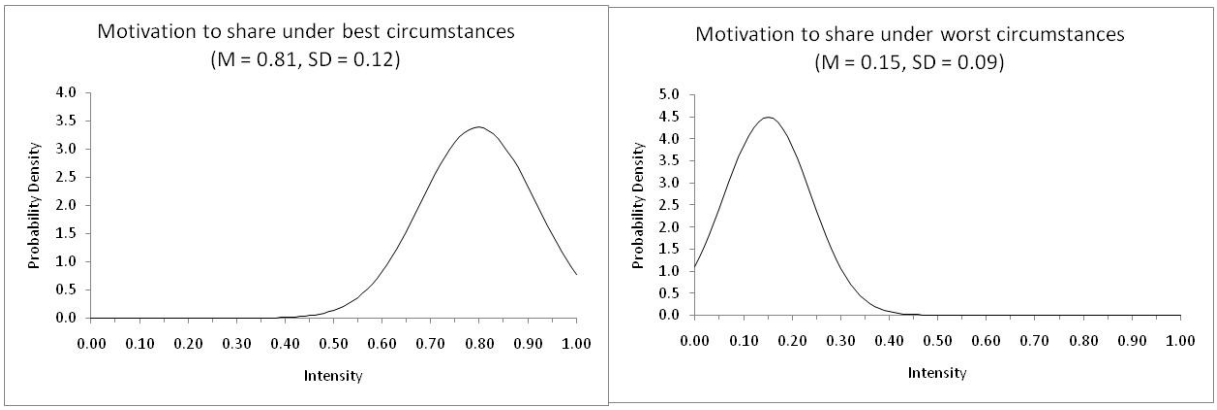


Figure 54: Motivation to share knowledge calculated for interacting agents that are equally motivated and those that have an opposite motivation to process the evidence.

Willingness to engage in trusting behaviour was encoded within agent's prior knowledge being updated with measures of positive and negative knowledge. For the recipient, this prior knowledge was a result of interacting with a "good", "bad" and "ugly" operator. In the preceding chapter, it was explained how and why these categories were chosen. Figure 55 illustrates the influence good and ugly operators had on recipient's willingness, representing the best and worst case respectively.

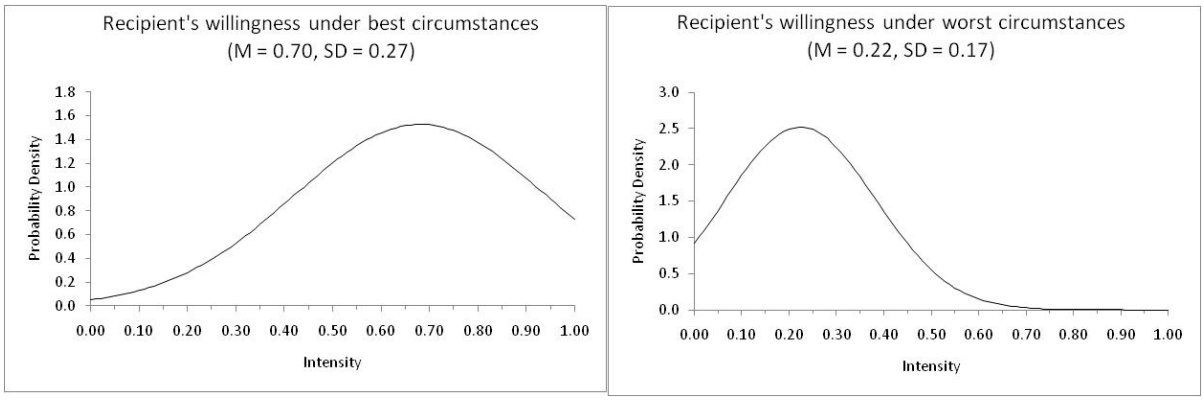


Figure 55: Recipient's willingness to engage in dialogue based on updates to their positive and negative prior knowledge.

Provider's positive and negative prior knowledge was updated as a function of the recipient using reward or coercive power, respectively. The rate at which this happened was dependent on whether the recipient's current receptivity was greater than their previous recorded receptivity. A change fitting with the recipient's policy would result in their excercising reward or coercive power (e.g. in the form of an increased or reduced annual fee to hold a waste management license, respectively). In the model, the recipient's policy was either to exercise power if current recipient's receptivity was greater than previous record of recipient's receptivity, greater than the past two records of recipient's receptivity, or greater than the past three records recipient's receptivity, representing a high, medium and low rate respectively. Hence, this was dependent on a multitude of parameters coming together to imbue the recipient with different rates of receptivity and therefore could not be simulated to illustrate the best and worst circumstances.

Four factors affect recipient's receptivity – propensity to trust, trustworthiness, referent power and willingness. Figures 53 and 54 describe the best and worst case scenarios for willingness, which is not directly influenced by personality types. Table 7 was developed from insights from Tables 5 and 6 and identifies the "Best" and "Worst" case personality types for each factor. This table illustrates that the aggressor has the greatest potential and the avoider type of personality has the least potential to influence agent receptivity through the effect they have on agent's propensity to trust, trustworthiness and referent power.

Table 7: "Best" and "Worst" case scenarios for different personality types

		Personality type			
		Negotiator	Aggressor	Submissive	Avoider
Propensity to trust	Best case	✓	✓		
	Worst case				✓
Trustworthiness	Best case		✓		
	Worst case				✓
Referent power	Best case	✓	✓	✓	
	Worst case				✓

Table 7 illustrates the potential influence that different personality types could have on agent receptivity in terms of Propensity to trust, Trustworthiness and Referent power. These factors directly influence agent receptivity.

Confidence building was modelled as explained in Chapter 7. Figure 56 shows the different rates at which confidence was gained as recipients and providers engaged in dialogue over the evidence being submitted. At the onset of each submission, recipient's confidence initializes at a certain value and then steadily increases as the provider makes multiple submissions of evidence. This was run for the "Best" and "Worst" case for agent receptivity and run under low and high levels of uncertainty; willingness, motivation, propensity to trust, trustworthiness and referent power.

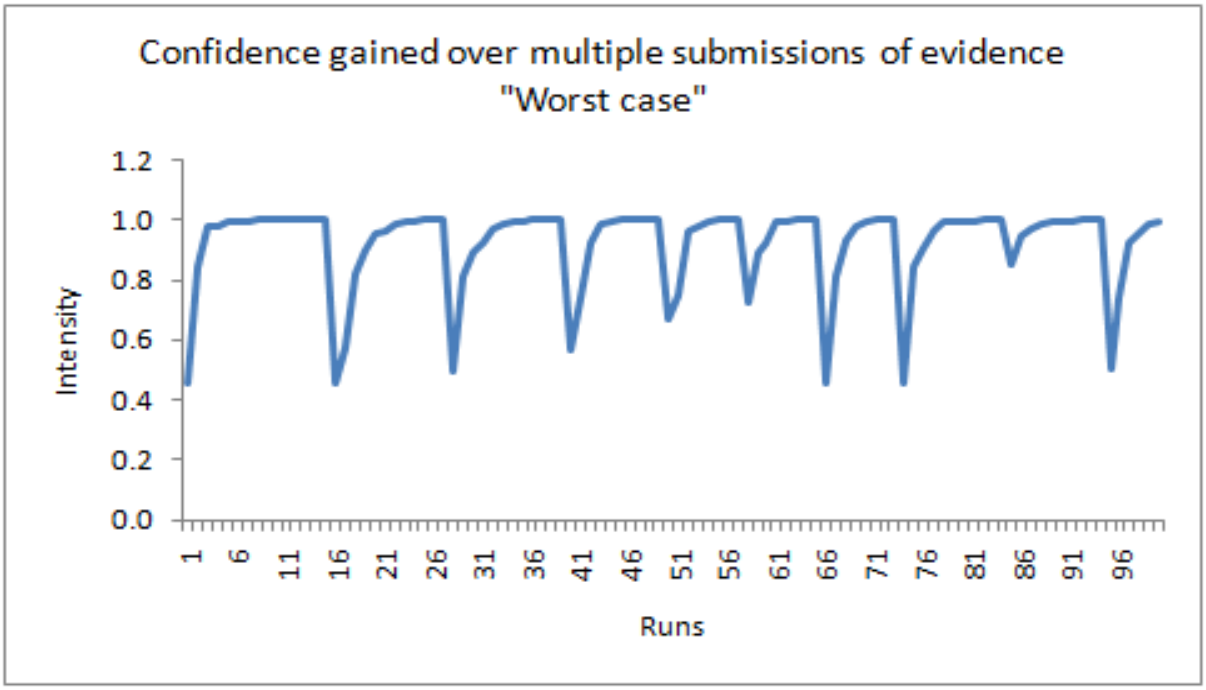


Figure 56: Confidence gained over multiple submissions of evidence in the "Worst case"

The different rate at which submissions could be made can have a substantial influence on the overall outcome. Figure 57 shows the corresponding results for the "best case" where confidence is attained much earlier.

Two factors affected the rate of the confidence building process:

- The initial level of confidence when the evidence was considered
- How quickly the regulator's confidence increases with time

These two factors would obviously be affected by the different personality types. In the "Worst case", the "avoider" regulator would not engage the operator frequently (as shown in Figure 55) which may result in slower rates of confidence building. From Figure 56, after confidence was attained for each piece of evidence considered there was

a substantial period of time before the next piece of evidence was considered. In addition, the regulator's confidence initializes at a relatively low level of intensity. As a result, the confidence building process takes longer.

In Figure 57, on the other hand, in the "best case" the "aggressor" regulator engages the operator regularly and has a higher probability of considering all the evidence presented quicker. The regulator's confidence is relatively higher at the initial stage and as such, the confidence building process is quickened.

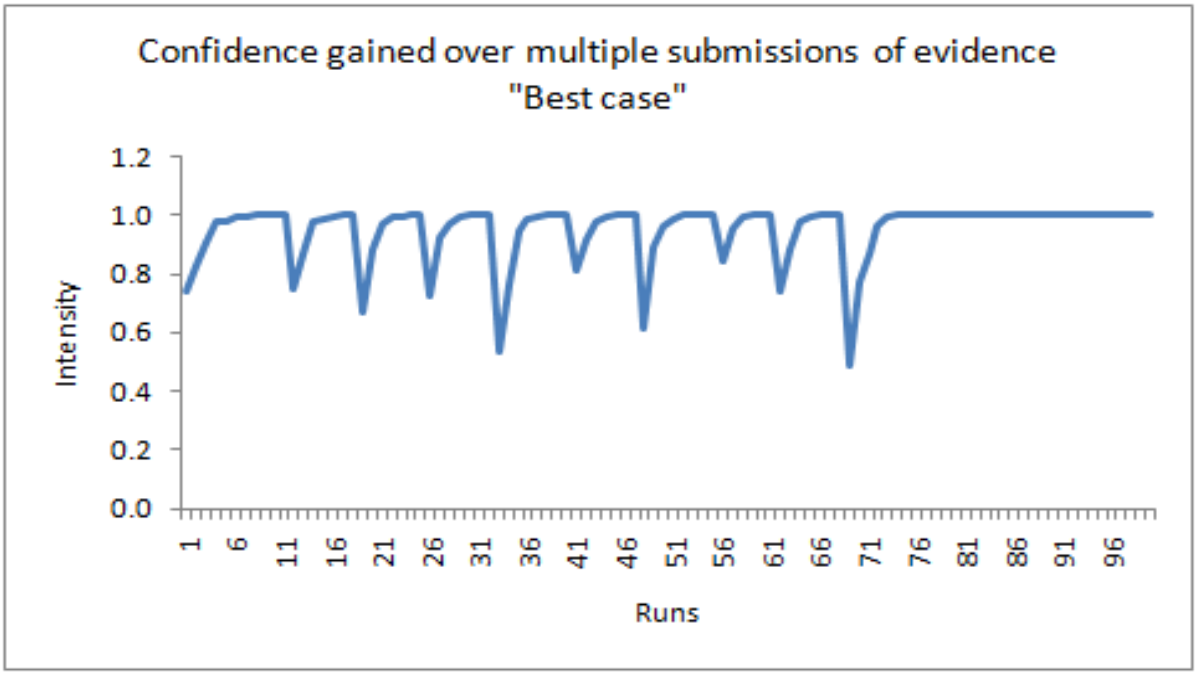


Figure 57: Confidence gained over multiple submissions of evidence in the "Best case"

8.2. Chapter summary and conclusions

In summary, this chapter has demonstrated a proof of concept by demonstrating the model can simulate known influences of personality and power in the context of the brokering process characterizing risk-based regulation. The simulation can model the influence participants have on confidence building and the rate at which this might occur according to changes in system parameters. As a form of validation, the simulation of a number of scenarios illustrates how the developed model replicate aspects of real world regulatory, policy development and environmental planning decisions.

Assessment of the influence that input random variables had on the variability of the output random variable. Adopting this approach, it was possible to determine those variables that agent receptivity was especially sensitive to. Making it possible to concentrate on controlling these variables with the aim of lowering their random variability.

This page is intentionally blank

Chapter 9

DISCUSSION

9.1 Introduction

This thesis illustrates, in principle, how it is possible to construct decision contexts using the concept of "automated decision makers" (e.g. Zhang and Zhang, 2007) to explore the influences of power structures and personality on the brokering of the scientific evidence that informs decisions on risk. Construction of a virtual decision-making environment has permitted this research to simulate and explore these factors in a way that would otherwise be cumbersome by studying real-time human behaviour. For example, by combining knowledge of individual and strategic choice, this thesis describes a decision environment that reflects the complex interaction of effects influencing humans (agents) when making decisions under uncertainty, whilst taking account of the behaviour of others. Moreover, this has allowed the variation of components of the decision-making environment, and of the actors themselves to attain a means of exploring the dynamic influence that power structure and key personalities might have on the regulator/applicant relationship, characterising the brokering of evidence in risk-based regulation.

This chapter provides a summary of the intellectual insights offered by this thesis. The primary focus is on evaluating the extent to which this research has been able to achieve

its aim: "*To provide a richer description of risk-based decision making in risk-based regulation by focusing on the social science aspects of decision making*".

9.2 The approach

In order to address the research aim it was necessary to devise a means of simulating insights contained within social science literature. To achieve this, a research framework was developed that informed the agent-based simulation used to bring together all these insights under one umbrella. The following sub-sections discuss the outcome and benefits of this approach.

In UK Government departments and agencies, technocratic processes are required to set out the decision-making process. An essential element of these frameworks is their ability to represent the brokering of scientific evidence through decision frameworks toward a final decision maker. The decision maker must then finalise their decision based on the relative strength, direction and weight associated with this evidence. Evidence is presented to decision makers as lines of evidence. These are consecutive lines of communication that stretch between sources of scientific evidence final decision makers. The three selected case studies provided a good spread of risk-based regulatory decision-making. These included a regulatory decision (the regulatory review of a post-closure safety case for nuclear waste disposal), an environmental planning decision (the disposal of avian influenza infected animal carcasses) and a policy development decision (dietary salt intake). Chapter 5 illustrates how these have been mapped out

using an existing methodology (developed by OXERA, 2000) and how this was expanded upon to incorporate the influence of power structure and personality.

Aforementioned, in Chapter 3, current risk management frameworks fail to account for the fact that the people making the decisions often must do so under conditions of uncertainty, limited resources (Eduljee, 2000) and/or contradictory evidence (Hood et al., 2004). Scholars have explained how this inherent omnipresence of uncertainty increases the level of subjectivity required to make decisions and have emphasized the role most participants play (Mayo and Hollander, 1994; Rothstein, 2006). By drawing on insights contained in existing literature, the two-agent model can, in principal, explore some of the complexities and nuances that characterise risk-based regulation.

In the Exploratory stage, it was revealed that the brokering of evidence consisted of participants either acting as either recipients or providers. Participants involved in this process engaged in three distinct stages:

- Receiving stage;
- Processing stage; and
- Passing on stage.

From the unstructured interviews, it was learnt that this was not a deterministic process but a dynamic process with the possibility of feedback. The brokering of scientific evidence for environmental decision making often has to be considered in parallel to other types of evidence such as political, social, costly and technical. In addition, evidence may be qualitative or quantitative in character. The type of individual also

plays a significant role in the brokering process based on their power and personality characteristics.

Conceiving the brokering process as existing within these three stages, this thesis specifically demonstrates how the known influences of power and personality (presented in Chapter 3) can be simulated in the context that characterises the brokering of scientific evidence.

Placing the likely influence of the Big Five personality traits have in context of the decisions has permitted marrying together the intrinsic nature of the decision maker with the extrinsic nature of power characterising an agent's world. This is a necessary step forward for practitioners wanting to account for the influence decision participants have on decision outcomes. As shown in Section 8.1, if the influence participants have on the brokering of evidence and confidence attached to a decision outcome is ignored then risk-based regulation faces a deteriorating transparency. This is especially true considering the growing number of risks that government must contend with. Moreover, regulatory resources allocated toward environment decision making have reached a plateau in some instances and declined in others, increasing the level of uncertainty characterising risk-based regulation (Hutter, 2005).

Power is both relational and reciprocal; a relationship must exist between participants, and it must be perceived by those it is exercised upon. This thesis illustrates how the relationship between intrinsic personality and extrinsic power relates to the dynamics of the brokering of evidence and knowledge. By simulating insights contained in the

power and personality literatures, the complexities that characterise a subject world can be captured (e.g. Mischel, 1968; 1995; 1999). Because of the level of complexity that this refers to, most scholars have sufficed to describe the existence of component level rules that seem important for making decisions. Some, however, have gone further to pinpoint characteristics that are important for specific conditions of a decision.

In the business psychology literature, there has been a growth in the use of psychometric tests for screening out employees that seem particularly ill-suited for roles within an organisation. However, these are largely limited in scope because of the extent to which they rely on the predictive power of personality. This limits their use because a measure of personality can at best only provide an indication of the types of behaviour that a particular person is likely to carry out over time. The classic example scholars often use to explain this is that an extrovert, will not always be outspoken, just that on most occasions they will be more outspoken than an introvert. The approach to investigate the influence participants have in the context of the decision is not new 'per se'. This thesis has attempted to place known influences of personality within the context of brokering of evidence. Scholars have used this 'person x situation' approach for a great number of years. However, there is a gap in knowledge regarding the influence specific traits have in the context of the brokering process in risk-based regulation. Now that the two-agent model has been developed, it could potentially explore the influence specific traits have on this brokering process.

One of the key issues to consider when investigating the brokering of scientific evidence is the relative influence different lines of evidence can have on a decision

outcome. This has been explicitly addressed in the body of the research presented in this thesis by drawing upon the logic set out in TESLA, the existing software developed by risk specialists Quintessa. Evidence-support logic has been used within TESLA and others to map out the logic of evidence-based decisions (as explained in Chapter 6). However, also explained in Chapter 6, this logic has not been used to map out the influence individuals have on decisions regarding the sufficiency of supporting evidence. This thesis has attempted to address this by developing a two-agent model that can account for the influence power and personality has on a participant's perception of sufficiency. It has also been suggested in Chapter 8 how this could be further developed and integrated within the evidence-support logic framework. Should this be achieved, it would be possible to carry out a sensitivity analysis to investigate which lines of evidence might be susceptible to the effect of participants' receptivity. This could reveal under what circumstances within the brokering process that participants' power and personality might be permitted to have a far greater impact. This would have obvious benefits for the disposal of avian influenza infected diseased animal carcases case study. In this case study, participants were not permitted to engage in extensive dialogue like in the nuclear waste disposal case study. The implications for getting it right the first time were therefore imperative. Updates to agents' negative prior knowledge, could render the relationship void by causing a significant drop in the recipient's confidence.

The development of agent-based models has implications for the selection of regulatory styles and of experts for expert elicitation panels. Risks must often be assessed and managed, with expert knowledge being used to fill the gaps in scientific evidence. Often

this consists of a group of experts that come together to express their opinion regarding the severity and characterization of risk. A number of techniques have been employed to facilitate this. The Delphi method, for example, sets out the process whereby experts are separated into groups to discuss particular aspects of a risk that must be managed. This is repeated until the researcher believes they have obtained the views and opinions of all the attending experts. Whilst such methods have merit, they can be labour intensive and time consuming. Moreover, they offer no guarantee that the make-up of each break-out group will not be dominated by a single individual or that the facilitator will be able to ensure all opinions are heard. The two-agent model could be developed to offer regulators the opportunity to explore the influence that experts will have on a decision outcome. This is illustrated in the dietary salt intake case study. The final decision whether to proceed with the recommended 6gm per day target was taken by a group of twelve experts. Further development of the agent-based model could illustrate the different impact participants might have on the group decision and the confidence this imbues them with.

9.3 Results from this study

Chapter 5 reconfirmed the variable influence different types of information can have throughout the course of a decision. Chapter 6 illustrates how agent's receptivity can be accounted for by drawing upon known power structure and personality influences. Chapter 7 provides a means of explaining the influence recipient's receptivity can have on a provider and thereby the likelihood that they will be able to imbue the recipients

with a greater measure of confidence regarding the sufficiency of the submitted evidence.

A novel aspect of the developed model is the platform it provides for users to consider the influence of power and personality that would otherwise be difficult to explore. In this thesis, agent-based modelling has permitted the simulation of the behaviour of heterogeneous autonomous agents that behave differently according to the evidence being submitted. The developed two-agent model was able to portray the "best" and "worst" personality types for different case studies as shown in Figures 50 to 52. It also describes how certain factors increase or decrease dynamically. For instance, the referent power of an "emotionally stable" provider or operator (as shown in Figure 52 for the "submissive" personality type) is shown to increase with time as he/she addresses all the regulators requests.

The complexity that characterizes the behaviour of participants in the brokering process is vast. To characterize this, variables' randomness (or unpredictability) could be incorporated in the model. Figures 53 to 55 show extreme "best" and "worst" cases with little spread for motivation to share and process while large spreads and less extremes for recipient's willingness. The spread is influenced by the number of possible factors (both internal and external) that could affect the various traits.

Dynamic simulations of the model have demonstrated the influences of the "best" and "worst" cases on the attainment of confidence over multiple submissions of evidence. Each supporting query could be considered as individual submissions of evidence. Once

the regulator's confidence is attained, the next piece of evidence is looked at. The "best" case involving the combination of receptive personality types attained confidence quicker for each deliberation than the "worst" case as shown in Figure 56.

Two factors that were found to influence confidence building rates were identified as being:

- The initial level of confidence when the evidence was considered; and
- How quickly the regulator's confidence increases with time.

The developed model was able to successfully demonstrate the influence of two extreme personality types on confidence building. "Avoiders" built confidence at a slower rate than "aggressors" as they did not openly divulge what types of evidence they required (as recipients) and were less attentive to what was being asked of them (as providers).

Such factors as low initial confidence at the start of the consultation in the Avian Influenza case study would have a greater impact on the decision outcome than either of the other cases. This is because the Avian Influenza case was an emergency response situation where regulatory decisions had to be made in a limited period of time. Conversely, the Nuclear Waste and Salt Intake case studies had significantly longer periods of time for decisions.

The rate of confidence building varied within the three case studies. In the Nuclear waste case, confidence would likely build at a slower rate because of the greater level of scientific uncertainty characterising the decision. The regulators also tend to be less

transparent with regards to the type of evidence that would imbue them with confidence in order to thoroughly assess the operator's competence in managing the associated risks. In contrast, in the Avian Influenza case study, confidence building would likely occur at a quicker rate because of the assessment and management of risk that is carried out in preparation for a disease outbreak.

Stakeholder consultation could affect both factors determining confidence building rates. It was important in the Salt Intake case study to attain a measure of influence over food manufactures. It played a significant role in both the Nuclear Waste and Avian Influenza case studies because of the levels of public dread associated with the risks being managed. The periods for stakeholder consultation also varied between the three case studies. In the Salt intake case study, stakeholder consultation was continuous throughout the brokering process. In the Avian Influenza case, stakeholder consultation was carried out early – ahead of the disease outbreak. In contrast, the Nuclear Waste case study stakeholder consultation was not permitted to occur until the latter end of the decision. The initial level and the rate at which confidence builds in the three case studies influences the impact it will have on confidence the regulator will have in the sufficiency the evidence supporting the final decision.

Stakeholder consultation had the potential to have the greatest impact in the Nuclear Waste case study. However, this was buffered by a period of informal submissions of evidence that occurred early in the brokering process. Similarly, in the Avian Influenza case study stakeholders were consulted early to balance the effect it would have during a disease outbreak.

For example, in the case of the post-closure safety case for nuclear waste disposal, the decision took four years to play out. Not only this, the level of access that would be required to provide similar insight is unpractical and unlikely ever to be granted.

9.4 General applications

Development of the two-agent model had scope for facilitating the planning and carrying out of scientific advisory panels. The use of advisory panels is a necessary component of modern environmental decision-making. They play an important role in addressing gaps in knowledge that can be time-consuming and costly. Generally, such reviews have been criticised. Some authors state that they only reveal additional uncertainties that further research can resolve (Powell, 1999). However, these panels are important in establishing knowledge concerning trust between internal colleagues, specifically between decision makers, policy makers and those responsible for carrying out the analysis of submitted evidence and developing options for appraisal. The two-agent model could be employed as a tool used in the planning of such panels.

Scholars also advice practitioners to maintain a realistic perspective about individual biases because independent advice is neither practical nor likely to be available (e.g. OXERA, 2000). Instead, practitioners of risk-based regulation are advised to manage such issues that require total independence. The developed two-agent model, at least in principle, has the scope to address some of these issues. The recipient's tendency to trust and the influence this has on their receptivity and confidence can be captured in the two-agent model.

As it stands, the two-agent model offers insights into the implications for the design of regulatory styles and selection/make-up of expert elicitation panels for complex risk decisions. Hence, development of this model would give regulators the opportunity to manipulate characteristics of decision makers and the decision context with respect to uncertainty. This could be used as a platform on which to consider influences that can be difficult to explore using human participants; hence, providing a valuable interaction between occupational psychology, agent-based simulation and the science of risk-based decision making.

Of particular interest to the literature on power and personality is the opportunity it provides to manipulate characteristics of the decision makers with respect to uncertainty. The model has clearly demonstrated that it is possible in this respect to vary the characteristics of decision makers and the decisions. It has achieved this by simulating insights contained within literature. This goes beyond such insight by placing them in the very real context of the decision. The two-agent model is structured to explore the relationship between the process by which specific evidence is actively brokered and the impact of personality on the receptivity of recipients.This is also of great interest for scholars investigating the role power and personality play in-group decision-making; providing a platform on which many otherwise disparate lines of reasoning could be brought together to give a wider picture of their implications for getting it right.

This research illustrates that it is possible to highlight specific aspects of each decision that are sensitive to the influence of power and personality (e.g., where belief is low and sufficiency is high). The developed model illustrates how the influence of motivational factors and general receptivity was substantially increased under greater levels of uncertainty if agents were uncertainty orientated. For example, this had obvious implications for the nuclear waste disposal case study that was particularly sensitive to the implications of the decision maker's power and personality because of their position within the hierarchy. Accounting for this, the model had the capacity to show how an otherwise strong line of evidence can have much less of an impact compared to a weak line of evidence because an agent's reduced receptivity.

9.5 Further development of the two-agent model

Further development of the two-agent model would allow it to be established as an exploratory tool that could facilitate the assessment and management of confidence building. The logic set out in the developed model could be run consecutively to represent the transfer of confidence up through lines of evidence and thereby providing a analysis of how sensitive decision outcomes are to personal and organisational features.

The two-agent model has demonstrated how it is possible to generate a measure of receptivity and relate this to how transparent an agent will be regarding their internal states. This could be developed further. By drawing upon the work set out by Ghasem-Aghee and Ören (2007) who demonstrated how agents could be modelled with a

measure of dynamic personality, relating the relative influence of facets to the characteristics of the situation. Such a development could rationalise the link between a recipient's perception and value judments made regarding the suffiency of submitted evidence.

Developing this into a multi-agent system would allow different strategies for building and maintaining a sustained level of confidence to be explored. Practitioners of risk-based regulation can struggle to maintain a sustained measure of confidence. The mismanagement of a disease outbreak, for example, has been shown to have long lasting effects that are difficuilt to overcome.

By conceptualizing recipients as sellers and providers as buyers of sufficiency within a multi agent model it would be possible to further explore the dynamics of the brokering process. Using the concept of dependency agents could be given the capacity to recognise novel aspects of submitted evidence and update their belief accordingly. This concept of giving memory to the agents would build on the work set out by Izquierdo et al. (2007) who demonstrated the value of giving agent's the capacity to learn from their experiences and avoid unsatisfactory outcomes. Moreover, agents could be shown to react based on their capacity to balance personal and organisational (e.g. following Kawakami et al., 2006) and thereby could explore the influence social networks have on the defusion of messages and formation of coalitions and informal networks within a risk-management framework.

This page is intentionally blank

Chapter 10

CONCLUSIONS AND FUTURE WORK

The aim of this work was to provide a richer description of the brokering of scientific evidence in risk-based regulation. This has been achieved through the development of a dynamic two-agent model of agent's receptivity.

Existing risk management frameworks were found to pay little homage to the fact that decisions made are acted upon by people, and as such, fail to account for the influence value judgments have in determining whether a risk is perceived to exist, and to what level.

A research framework capable of mapping out the logic of the brokering process was developed. This was achieved by exploring the flow of information within three real-world case studies. The brokering process was found to consists of three stages; the receiving stage, the processing stage, and the passing-on stage, which were not deterministic but dynamic with the possibility of feedback between the three stages.

Building upon evidence-support logic the developed research framework is capable of exploring the influence participants have on the brokering of evidence. This was achieved by incorporating aspects of power and personality to inform agent's receptivity. Receptivity would influence judgements regarding the confidence attained in submissions of evidence.

The recipient's tendency to trust and the influence this has on their receptivity and confidence can be captured in developed two-agent model. Four factors were used to determine agent's receptivity – motivation, propensity to trust, trustworthiness and referent power. The dynamic two-agent model was able to give agents variable personalities which had varied influences on these factors. "Best" and "Worst" personality types towards building confidence were identified as the "aggressor" and "avoider" type, respectively. Discussions showed how this related to industrial-based case studies and provided insights into how individuals can in fact influence decision making in different scenarios.

The two-agent model is a novel development for risk-based regulation. The developed two-agent model can account for the influence power and personality has on a participant's perception of sufficiency. The model improves the transparency in the brokering process and has clearly demonstrated that it is possible to vary the characteristics of decision makers and the decisions by simulating insights contained within literature.

Further work may be carried out to extend the model to a multi-agent model that could describe the influence of power and personality in group decision making; this may include coalitions, informal networks.

The developed model is a step toward a fully-fledged multi-agent system Drawing upon existing multi-agent systems recipients could be conceptulised as buyers and providers

as sellers of sufficiency. The comodity they would broker would be different types of evidence, the value recipients place in it would be reflected as variable measure of confidence. Using the concept of dependency agents could be given memory, permitting them to update their measure of receptivity, and thereby confidence according to the novelty aspects of evidence being submitted.

This page is intentionally blank

REFERENCES

Abrams, L.C.; Cross, R.; Lesser, E.; Levin, D.Z. (2003) Nurturing interpersonal trust in knowledge-sharing networks. *Academy of Management Executive* **17**(4), 64–77.

Alkemade, F.; Poutrè, H.L.; Amman, H. (2003) Intermediaries in an electronic trade network [Extended Abstract], Proceedings of the 4th ACM conference on Electronic commerce, June 09-12, 2003, San Diego, CA, USA

Andrews, C.J.; Hassenzahl, D.M.; Johnson, B.B. (2004) Accommodating Uncertainty in Comparative Risk. *Risk Analysis,* **24**(5): 1323-1335.

Argyle M.; Hills P. (2000) Religious experiences and their relations with happiness and personality, *International Journal For the Psychology of Religion.*

Back, M.D.; Schmukle, S.C.; Egloff, B. (2006) Who is late and who is early? Big Five personality factor and punctuality in attending psychological experiments, Journal of Research in Personality, **40**: 841-848.

Bakker, M., Leenders, R., Gabbay, S., Kratzer, J. & van Engelen, J. (2006). Is Trust Really Social Capital? Knowledge Sharing in Product Development Projects, *The Learning Organization,* **13**(6), 594-605.

Bartlett, F. C. (1932). *Remembering: A study in experimental and social psychology*. Cambridge: Cambridge University Press.

Barrick, M.R.; Mount, M.K.; Stewart, G.L. (1998) Five-factor model of personality and performance in jobs involving interpersonal interactions. *Human Performance,* **22**(2-3): 145-165.

Becerra, M.; Gupta, A.K. (2003) ‘‘Perceived trustworthiness within the organization: the moderating impact of communication frequency on trustor and trustee effects’’, *Organization Science*, **14**(1): 32-44.

Beecham, J.A.; Engelhard, G.H. (2007) Ideal free distribution or dynamic game? An agent-based simulation study of trawling strategies with varying information. *Physica A*, **384**: 628–646

Belaya, V.; Török, T.; Hanf, J. (2008) Recognizing the Links between Power and Trust in Managing Supplu Chain Relationships. 12th Congress of the European Association of Agricultural Economics – EAAE

Bell, S.; McGillivray, D. (2000) Environmental Law (5th), Blackstone Press.

Bello-Dambatta, A.; Farmani, R.; Javadi, A.A.; Evans, B.M. (2009) The analytical hierachy process for contaminated land management **23**(4):433-441.

Bem, D.J. (1983) Toward a response style theory of persons in situations. In R. A. Dienstbier & M. M. Page (Eds.), *Nebraska Symposium on Motivation 1982: Personality--Current theory and research* (Vol. 30, pp. 201-231). Lincoln: University of Nebraska Press.

Benbow, S.; Metcalfe, R.; Egan, M. (2006) Handling uncertainty in safety assessments for long term geological storage of CO_2. In: N. Rokke, O. Bolland and J. Gale, Editors, *Proceedings of the Greenhouse Gas Control Techniques Conference (GHGT8)* Trondheim, June 2006 (2006).

Berg, B.L. (1995) *Qualitative Research Methods for the Social Sciences (2nd Edn)*. Needham Heights, Mass.: Allyn and Bacon

Berman, M.; Nicolson, C.; Kofinas, G.; Tetlichi, J.; Martin, S. (2004) Adaptation and sustainability in a small arctic community: Results of an agent-based simulation model, *Arctic*, **57**(4): 401-414.

Berry, R. S. Y. 1999. *Collecting data by in-depth interviewing.* Paper presented at the British Educational Research Association Annual Conference, University of Sussex at Brighton, September 2-5. BERA 99. Retrieved February 14, 2006 from http://www.leeds.ac.uk/educol/documents/000001172.htm.

Berry, C.M.; Ones, D.S.; Sackett, P.R. (2007) Interpersonal deviance, organizational deviance, and their common correlates: A review and meta-analysis. *Journal of Applied Psychology*, ***92:*** 410–424.

Blacker, F. (1995) Knowledge, knowledge work and organizations: an overview and interpretation. *Organization Studies*, **16**(6): 1021-46.

Blackman, T. (1998) Towards Evidence-Based Local Government: Theory and Practice. *Local Government Studies*, **24**(2): 56-70.

Blass, T. (1991) Understanding behavior in the milgram obedience experiment: the role of personality, situations, and their interactions. *Journal of Personality and Social Psychology***, 60**(3): 398-413

Boholm, Å. (2003). The cultural nature of risk: can there be an anthropology of uncertainty? *Ethnos*, **68**(2), 159-178.

Bohte, S.M., Gerding, E., Poutr'e, H.L.(2001). Competitive market-based allocation of consumer attention space. In *Proceedings of the 3rd ACM Conference on Electronic Commerce,* Tampa, FL, USA. 202–205.

Bone, C.; Dragicevic, S.; (2010) Simulation and validation of a re-inforcement learning agent-based model for multi-stakeholder forest management. *Computers, Environment and Urban Systems*, **34**(2), pp 162-174.

Bonnevay, S.; Kabachi, N.; Lamure, M.; (2005) Agent-based simulation of coalition formation in cooperative games, Intelligent Agent Technology, *IEEE/WIC/ACM International conference*, pp 136-139.

Borkenau, P.; Riemann, R.; Spinath, F.M.; Angleitner, A. (2006) Genetic and environmental influences on person x situation profiles. *Journal of Personality*, **74**(5): 1451- 1480.

Bowden, R.A. (2004) "Building confidence in geological models". In Curtis, A. And Wood, R. (Eds.) Geological Prior Information. Geological Society, London, Special Publications.

Bowers, K.S. (1973) Situationism in psychology: an analysis and a critique. *Psychological Review*, **80**: 307-336.

Bradshaw, G.A.; Borchers, J.G. (2000) Uncertainty as Information: Narrowing the Science-policy Gap. *Conservation Ecology,* **4**(1): 7.

Brailsford, S. and Schmidt, B. (2003), "Towards incorporating human behaviour in models of health care systems: An approach using discrete event simulation", *European Journal of Operational Research,* vol. 150, no. 1, pp. 19-31.

BRC (2006) Risk, Responsibility and Regulation. Whose risk is it anyway?, October, London, Better Regulation Commission.

Broom, A. (2005) Using qualitative interviews in CAM research: A guide to study design, data collection and data analysis. *Complementary Therapies in Medicine*, **13**: 65-73.

Brown, D.G., Page, S.E., Riolo, R., Rand, W., 2004. Agent-based and analytical modeling to evaluate the effectiveness of greenbelts. *Environmental Modelling & Software*, **19**: 1097-1109.

Bryman, A. (1988) *Quantity and Quality in Social Research*. London: Unwin Hyman

Bryman, A. (2001) *Social Research Methods,* Oxford University Press: Oxford

Burke, L.A.; Witt, L.A. (2004) Personality and high-maintenance employee behavior. *Journal of Business and Psychology*, **18**: 349-363.

Burgess, R.G. (1984). *In the field: An introduction to Field Research*. London: Unwin

Cabinet Office (1999) *Modernising government,* Presented to Parliament by the Prime Minister and the Minister for the Cabinet Office by Command of Her Majesty. Updated 2002. White Paper. Stationery Office March 1999. Available from (http://www.archive.official-documents.co.uk/document/cm43/4310/4310.htm) Crown Copyright, London.

Camerer, C. F. (2003). Behavioral game theory: Experiments in strategic interaction. Princeton, NJ7 Princeton University Press.

Cattell, R.B.; Cattell, A.K.S.; Rhymer, R.M. (1947) P-technique demonstrated in determining psychophysical source traits in a normal individual. *Psychometrika*, **12**: 267–288.

Cherry, F.; Byrne, D. (1977) Authoritarianism. *Personality variables in social behavior*, Erlbaum, Hillsdale, p. 109–133

Cheung, Bro-Shiuan.; Wang, Shu-Hsun.; Tsai, Sung-Chun.; Chou, Li-Fang. (unpublished) How openness to experience can facilitate knowledge sharing: an interpersonal trust perspective. Available from (http://140.112.161.103/gdoc/d93227102B.pdf).

Content, N. (2005) Securing corporate buy-in to business risk management. Proceedings from the AwwaRF Workshop *Risk analysis strategies for better and more credible decision-making*. Banff, Canada

Costa Jr., P.T.; McCrae, R.R. (1992) *NEO PIR-R^{TM} – Revised NEO Personality Inventory (NEO PI-R^{TM}) and NEO Five-Factor Inventory (NEO-FFI) – Professional Manual.* PAR Psychological Assessment Resources, Inc., Odessa, Florida.

Court, M.; Pittman, J.; Alexopoulos, C.; Goldsman, D.; Kim, S.-H.; Loper, M.; Pritchett, Haddock, J. (2004) A framework for simulating human cognitive behaviour and movement when predicting impacts of catastrophic events. Proceedings – Winter Simulation Conference, **1**: 830-838.

Creswell, J.W. (1994) *Research Design; Qualitative and Quantitative Approaches* Thousand Oaks, London, New Delhi: Sage

Cui, W. And Blockley, D.I. (1990) "Interval probability theory for evidential support." *International Journal of Intelligence Systems*, **5**: 183-192.

Dahl, R.A. (1957) The Concept of power, *Behavioral Science,* **2**(3): 201-214.

Davenport, T.H.; Prusak, L. (1998) *Working Knowledge.* Cambridge, MA: Harvard Business School Press.

Davies, G.J.; Kendall, G.; Soane, E.; Li, J.; Charnley, F.; Pollard, S.J.T. (2010) Regulators as 'agents': power and personality in risk regulation and a role for agent-based simulation. *Journal of Risk Research*, 14 September 2010: DOI: 10.1080/13669877.2010.486075

Dawson, C. (2007) A Practical Guide to Research Methods: A User-friendly Manual for Mastering Research Techniques and Projects (paperback). How To Books Ltd, 3rd Ed.

Deisler, P.F.Jr. (1988) The risk management – risk assessment interface. *Environmental Science and Technology*, **22**: 15-19.

DePaulo, P. (2000) Sample size for qualitative research. Quirk Marketing Research Review.

Dempster, A. P. (1976) Upper and lower probabilities included by a multivalued mapping. *The Annals of Mathematical Statistics*, **38**(2): 325 – 339.

Deng, P.S. (2007) A sharing-driven continuous-learning approach to knowledge management in knowledge-intensive small firms. *WSEAS Transactions on Information Science and Applications*, **4**(4): 850-858.

Denissen, J.J.A.; Penke, L. (2008) Motivational individual reaction norms underlying the Five-Factor model of personality: First steps towards a theory-based conceptual framework. *Journal of Research in Personality*, **42**(5): 1285-1302.

DETR (2000) Environment Agency and Institute for Environment and Health. Guidelines for environmental risk assessment and management-revised departmental guidance, The Stationery Office, London, 2000, 88pp.

Digman, J.M. (1990) Personality structure: Emergence of the five-factor model. *Annual Review of Psychology,* 41 :417–440.

Dimuro, G.P.; Costa, A.C.R.; Gonçalves, L.V.; Hubner, A. (2006) Regulating Social Exchanges Between Personality-based Non-transparent Agents. Escola de Informatica, Universidade Catolica de Pelotas, Brazil.

Dirks, K.T.; Ferrin, D.L. (2001) The role of trust in organizational settings. *Organization Science*, **12**: 450-467.

Duerden, S.; Yearley, R.; Bennett, D. (2003) Drigg 2002 Post-Closure Safety Case Review Plan - Assessment of the Post-Closure Safety Case for the Drigg Low-Level Radioactive Waste Disposal Site, Environmental Policy – Risk and Forecasting Guidance Note No. 44, Environment Agency, Reading, UK.

Eduljee, G.H. (2000) Trends in risk assessment and risk management, *The Science of the Total Environment*, **249**: 13-23.

Elghali, L. (2002) Decision Support Tools for Environmental Policy Decisions and their Relevance to Life Cycle Assessment. –Working Paper, Centre for Environmental Strategy, University of Surrey, August 2002.

El-Ghonemy,H.; Watts, L.; Fowler, L. (2005) Treatment of uncertainty and developing conceptual models for environmental risk assessments and radioactive waste disposal safety cases, *Environment International,* **31** (2005): 89–97.

Endler, N.S. (1984) Interactionism. In N. S. Endler & J. McV. Hunt (Eds.), Personality and the behavioral disorders (2nd ed., Vol. 1, pp. 183-217). New York: Wiley.

Environment Agency (2005) Environment Agency, Delivering for the environment: a 21st century approach to regulation, Environment Agency, Bristol.

Epstein, S. (1996) Recommendations of the future development of personality psychology. *Journal of Research in Personality,* **30**: 435-446

Epstein, J.M (1999) Agent-based models and generative social science. *Complexity* 4/5, pp. 41–60.

Epstein, J.M. (2006), Generative Social Science; Studies in agent-based computational modelling. Princeton University Press.

Evans, A.M.; Revelle, W. (2008) Survey and behavioural measurements of interpersonal trust. *Journal of Research in Personality*, **42**(6): 1585-1593.

Eysenck, S.B.G.; Eysenck, H.J. (1980) Impulsiveness and Venturesomeness in Children. *Personality and Individual Differences* 1: 73–78.

Farmani, R.; Henriksen, J.H.; Savic, D. (2008) An evolutionary Bayesian belief network methodology for optimum management of groundwater contamination. *Environmental Modelling and Software* **24**(3):303-310.

Feller W. (1971) W. Feller In: (second edition ed.) *An Introduction to probability theory and its applications*. Vol. 2, Wiley, New York.

Flaherty, S.; Moss, S.A. (2007) "The impact of personality and team context on the relationship between workplace injustice and counterproductive work behavior". *Journal of Applied Social Psychology*, **37**(11): 2549-75.

Fleeson, W. (2007) Situation-based contingencies underlying trait-content manifestation in behavior. *Journal of Personality* **75:** 825–862. View Record in Scopus | Cited By in Scopus (4)

Foley, L.; Ball, L.; Hurst, A.; Davis, J. And Blockley, D. (1997) "Fuzziness, incompleteness and randomness: classification of uncertainty in reservoir appraisal". *Petroleum Geoscience*, **3:** 203-209.

Fontana, A., & Frey, J. H. (2005) The interview: From neutral stance to political involvement. N. K. Denzin, & Y. S. Lincoln (editors), *The Sage Handbook of Qualitative Research* (3rd ed,). Thousand Oak: Sage Publications.

French, S.; Bedford, T.; Atherton, E. (2005) Supporting ALARP decision making by cost benefit analysis and multiattribute utility theory. *Journal of Risk Research*, **8**(3): 207-233.

French, J.R.P.; Raven, B. (1959) The bases of social power, *Studies in Social Power,* 150-167.

Fridhandler, B.M. (1986) Conceptual note on state, trait, and the state-trait distinction. *Journal of Personality and Social Psychology* **50**: 169–174.

Funder, D.C. (1996) Waiting for the big one. *Journal of Research in Personality*, **30**(3): 454-455.

Funtowitz, S.; Ravert, J. (1996) 'Risk management, Post MNormal Science and Extended Peer Review' in C. Hood and D. Jones (eds) Accident and Design: Contemporary Debates in Risk Management. London; Bristol, Pa.: UCL Press.

Gambetta, D. (1988) Trust: Making and breaking cooperative relations. Oxford, Uk: Basil Blackwell.

Ghasem-Aghaee, N.; Ören, T.I. (2003) Personality Representation Processable in Fuzzy Logic for Human Behaviour Simulation, Proceedings of the 2003 Summer Computer Simulation Conference, Montreal, Canada, pp 11-18.

Ghasem-Aghaee, N.; Ören, T.I. (2007) Cognitive complexity and dynamic personality in agent simulation. Journal of Computers in human behaviour Volume 23, Issue 6, pp 2983-2997.

Golafshani, N. (2003). Understanding Reliability and Validity in Qualitative Research. *The Qualitative Report, 8*(4), 597-607.

Goldberg, L.R. (1990) An alternative "Description of personality": The Big-Five factor structure. *Journal of Personality and Social Psychology,* **59**: 1216-1229.

Gonzalez, R.A. (2009) Crisis response simulation combining discrete-event and agent-based modeling. *Proceedings of the 6th International ISCRAM Conference – Gothenburg, Sweden, May 2009.* J. Langdren and S. Jul, eds.

Gotts, N.M.; Polhill, J.G. (2009) Narrative Scenarios, Mediating Formalisms, and the Agent-Based Simulation of Land Use Change. *Conference on Epistemological Perspectives on Simulation* EPOS06, pp. 99-116.

Graziano, William G., Habashi, M.M.; Sheese, B.E.; Tobin, R.M. (2007) "Agreeableness, empathy, and helping: A person X situation perspective." *Journal of Personality and Social Psychology*, **93**(4): 583-599.

Guzy, MR.; Smith, CL.; Bolte, JP.; Hulse, DW.; Gregory S.V (2008) Ecology and Society Vol 13 no 1

Haddawy, P.; Dhananaiyapergse, K.; Kaewpitakkun, Y.; Bui, T. (2004) Data-Driven Agent-Based Simulation of Commercial Barter Trade. *Proceedings of the IEEE/WIC/ACM International Conference on Intelligent Agent Technology (IAT'04).*

Hall J.W.; Blockley D.I.; Davis, J.P. (1998) Uncertain inference using interval probability theory, *International Journal of Approximate Reasoning*, **19**(3-4):247-264.

Hampton, P. (2005) *Reducing administrative burdens: effective inspection and enforcement*, HM Treasury.

Handy, C. (1999) Understanding Organizations. London: Penguin Books.

Hanf, K. (2006) Regulatory Structures: Enforcement as Implementation. European Journal of Political Research, **10**(2): 159-172.

Hansen, M.T. (1999) The search-transfer problem: The role of weak ties in sharing knowledge across organization subunits. *Administrative Science Quarterly*, **44**: 82-111.

Henesey, L.; Davidsson, P.; Persson, J. (2006) Evaluating container terminal transhipment operational policies: An agent-based simulation approach. *WSEAS Transactions on Computers*, **5**(9): 2090-2097.

Hills, P.; Argyle, M. (2001) Emotional stability as a major dimension of happiness. *Personality and Individual Differences*, **31**(8): 1357-1364.

HM Government (2005) Guidelines on Scientific Analysis in Policy Making.

Hodson,G.; Sorrentino, R.M. (1999) Uncertainty orientation and the Big Five personality Structure. *Journal of Research in Personality*, **33**(2): 253-261.

Hood, C; Rothstein, H.; Baldwin, R. (2004) The Government of Risk: Understanding Risk Regulation Regimes, Oxford University Press: New York.

Hong, R.Y.; Paunonen, S.P.; Slade, H.P. (2008) Big Five personality factors and the perception of behavior: A multitrait-multimethod approach. *Personality and Individual Differences,* **45**(2): 160-166.

House of Lords, Select Committee on Science and Technology 1999-2000 (2000) *Science and Society, 3rd report, HL Paper 38*, The Stationary Office, London.

House of Lords, Select Committee on Economic Affairs, (2006) *Government policy on the management of risk, Volume 1, HL 183-I,* The Stationary Office, London 40pp.

Hutter, B.M. (2005) *The Attractions of risk-based regulation: accounting for the emergences of risk ideas in regulation, Discussion Paper no. 33*, ESRC Centre for Analysis of Risk Regulation, London School of Economics and Political Science.

ILGRA Interdepartmental Liaison Group on Risk Assessment (1998), *Risk Assessment and Risk Management: Improving Policy and Practice within Government Departments*; HSE Books: Suffolk, UK, available from: http://www.hse.gov.uk/dst/ilgra/minrpt1a.htm

Irving, A.D. (1992) Stochatistic sensitivity analisys. *Applied Mathematical Modelling,* **16**(1): 3-15.

Ivancevich, J.M.; Matteson, M.T. (1999) *Organisational Behaviour and Management.* McGraw Hill, Boston, MA.

Izquierdo, I.R., Gotts, N.M. and Polhill, J.G., 2003. FEARLUS-W: an agent-based model of river basin land use and water management, Framing Land Use Dynamics: integrating knowledge on spatial dynamics in socio-economic and environmental systems for spatial planning in western urbanized countries, University, The Netherlands.

Izquierdo L.R.; Izuierdo S.S.; Gotts N.M.; Polhill J.G (2007), Transient and asymptotic dynamics of reinforcement learning in games. Journal of Games and Economic Behaviour Volume 61, Issue 2, November 2007, pp 259-276.

John, O.P. (1990) The "Big Five" factor taxonomy: dimensions of personality in the natural language and in questionnaires. In: L.A. Pervin (Ed.), *Handbook of personality: Theory and research* (pp. 66-100). New York: Guilford Press.

John, O.P.; Srivastava, S. (1999) The Big-Five Trait taxonomy: history, measurement, and theoretical perspectives. In: Pervin, L.A. and John, O.P. (eds), *Handbook of personality: Theory and research* (2nd ed. – pp. 102-138). New York: Guilford Press.

Johnson, G. (1992) Managing strategic change - strategy, culture and action. *LongRange Planning*, 25(1), 28-36.

Johnson, J.A. (1999) Persons in situations: distinguishing new wine from old wine in new bottles. *European Journal of Personality*, **13**: 443-453.

Kala, Z.; Kala, J. (2009) Variance-based sensitivity analysis of stability problems of steel structures using shell finite elements and nonlinear computation methods, **4**(3):89-114.

Kammrath, L.K.; Mendoza-Denton, R.; Mischel, W. (2005) Incorporating if… then… personality signatures in person perception: beyond the person-situation dichotomy. *Journal of Personality and Social Psychology*, **88**(4): 605-618.

Kanter, R.M. (1979) Power failure in management circuits, *Harvard Business Review,* **57(**4): 65-75.

Karkoulian S., Messarra, L.Mohamad, S. (2009) Correlates of the bases of power and the big five personality traits: an empirical investigation, *Journal of Organizational Culture, Communications and Conflict*

Kawakami, H.; Tanizawa, T.; Katai, O.; Shiose, T. (2006) Multi-agent Simulation for Voting by Small Community. *SICE-ICASE International Joint Conference 2006, Oct. 18-21, 2006, Bexco, Busan, Korea.*

Kearney, J.A. (2007) Transcultural journeys in Mahjoub's historical novels. *Research in African Literatures*, **38**(4): 127-140.

Kijima, K.; Hirata, H. (2005) Diffusion of word-of-mouth in segmented society: Agent-based simulation approach. *Lecture Notes in Artificial Intelligence (Subseries of Lectures Notes in Computer Science)*, **3397**: 198-2006.

Kim, Y.S. (2007) Maximizing sellers' welfare in online auction by simulating bidders' proxy bidding agents. *Expert Systems with Applications*, **32**: 289-298.

Kirk, D.D.; McIntosh, K.; Walmsley, A.M.; Peterson, R.K.D. (2005) Risk analysis for plant-made vaccines, *Transgenic Research*, **14**: 449-462.

Klugl, F.; (2001) Multi-Agent Simulation-Concepts, Tools, Application, Addison Wesley, Munich (in German).

Korhonen, M.H.; Litmanen, H.; Rauramaa, R.; Vaisanen, S.B.; Niskanen, L.; Uusitupa, M. (1999) Adherence to the salt restriction diet among people with mildly elevated blood pressure. *European Journal of Clinical Nutrition,* **53**: 880–885.

Kramer, R.; Tyler, T. Eds. (1996) Trust in organizations: Frontiers of theory and research. Thousand Oaks, CA: Sage.

Lauriola, M. and Levin, I. P. (2001), "Personality traits and risky decision-making in a controlled experimental task: An exploratory study", *Personality and Individual Differences,* vol. 31, no. 2, pp. 215-226.

Lee, K.; Ashton, M.C.; Shin, K.-H. (2005) Personality Correlates of Workplace Anti-Social Behavior. *Applied Psychology: An International Review*, **54**(1): 81-98.

Lee, S K J. (1992) Quantitative versus qualitative research methods – Two approaches to organisation studies. *Asia Pacific Journal of Management*, **9**(1): 87-94.

Levin, D.Z.; Cross, R. (2004) The Strength of Weak Ties You Can Trust: The Mediating Role of Trust in Effective Knowledge Transfer. *Management Science* **50**(11): 1477-90.

Levin, D.Z.; Whitener, E.M.; Cross, R. (2006) Perceived Trustworthiness of Knowledge Sources: The Moderating Impact of Relationship Length. *Journal of Applied Psychology* **91**(5): 1163–71.

Liao, L-F. (2008a) Knowledge-sharing in R&D departments: a social power and social exchange theory perspective. *The International Journal of Human Resource Management,* **19**(10): 1881-1895.

Liao, L-F. (2008b) Impacts of manager's social power on R&D employees' knowledge-sharing behaviour. *Int. J. Technology Management*, **41**(1/2): 169-182.

Liao, H.; Chuang, A. (2004) A multilevel investigation of factors influencing employee service performance and customer outcomes. Academy of Management Journal, **47**(1): 41-58

Liu, C.C. (2008) The Relationship between Machiavellianism and Knowledge Sharing Willingness. *Journal of Business and Psychology*, **22**: 233-240.

Liu, F.C.S. (2007) Constrained opinion leader influence in an electoral campaign season: Revisiting the two-step flow theory with multi-agent simulation. *Advances in Complex Systems*, **10**(2): 233-250.

Long , J.; Fischhoff, B. (2000) Setting risk priorities: A formal model. *Risk Analysis*. **20**(3): 339-351.

Lowell, R.B.; Culp, J.M.; Dubé, M.G. (2000) A weight-of-evidence approach for nothern river risk assessment: Integrating the effects of multiple stressors. *Environmental Toxicology and Chemistry*, **19**(4): 1182-1190

Majone, G. (1989) Evidence, Argument and Persuation in the Policy Process. New Haven: Yale University Press.

Marreiros, G.; Santos, R.; Ramos, C.; Neves, J.; Bulas-Cruz, J. (2008) ABS4GD: A Multi-agent System that Simulates Group Decision Processes Considering Emotional and Argumentative Aspects. *AIII Spring Symposium Series*, *Stanford University, USA*.

Martins, N. (2002) A model for managing trust. *International Journal of Manpower*. **23**(8): 754-769.

Mayo, D.G.; Hollander, R.D. Eds. (1994) Acceptable Evidence – Science and Values in Risk Management, Oxford University Press: New York.

Mayer, R.C.; Davis, J.H.; Schoorman, F.D. (1995) An integrative model of organizational trust. *Academy of Management Review*, **20**(3): 709-734.

McAllister, D.J. (1995) Affect- and cognition-based trust and as foundations for interpersonal cooperation in organizations. *Academy of Management Journal*, **38**: 24-59.

McEvily, B.; Peronne, V.; Zaheer, A. (2003) Trust as an Organizing Principle, *Organization Science*, **14**: 91–103.

Mcintosh, B. S., P. Jeffrey; M. Lemon and N. Winder (2005), On the design of computer based models for integrated environmental science, *Environmental Management,* **35**(6): 741-752.

Mendonça, D. (2008) Agent-Based Simulation. Risk management in Civil Engineering, Advanced course.

Millington J.; Romero-Calcerrada R.; Wainwright J.; Perry G. (2008) An Agent-based Model of Mediterranean Agricultural Land-Use/Cover Change for Examining Wildfire Risk, *Journal of Artificial Societies and Social Simulation*, **11**(44).

Minichiello, V., Aroni, R., Timewell, E. & Alexander, L. (1990). *In-Depth Interviewing: Researching People*. Melbourne: Longman Cheshire.

Mischel, W. (1968) Situation vs personality debate.

Mischel, W. (1999) Implications of person-situation interaction: getting over the field's borderline personality disorder. *European Journal of Personality*, **13**:455-461

Mischel, W.; Shoda, Y. (1995) A cognitive-affective system theory of personality: reconceptualising situations, dispositions, dynamics, and invariance in personality structure. *Psychological Review,* **102**(2): 246-268.

Mizuta, H.; Steiglitz, K. (2000) Agent-Based Simulation of Dynamic Online Auctions. *Proceedings of the 2000 Winter Simulation Conference, J.A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, eds.*

Mizuta, H.; Yamagata, Y. (2001) Agent-Based Simulation and Greenhouse Gas Emissions Trading. *Proceedings of the 2001 Winter Simulation Conference, B.A. Peters, J.S. Smith, D.J.Medeiros, and M.W. Rohrer, eds*.

Molm, L.D. (1997) Risk and power use: Constraints on the use of coercion in exchange. *American Scociological Review*, **62**: 113-133

Montibeller G.; Franco LA.(2009) Multi-criteria decision analysis for strategic decision making: content and process. Handbook of multi-criteria analysis. Springer 2010, Chapter 2 pp 25-48

Monticino, M.; Acevedo, M.; Callicott, B.; Cogdill, T.; Lindquist, C. (2007) Coupled human and natural systems: A multi-agent-based approach. *Environmental Modelling & Software*, **22**(5): 656-663.

Mooradian, T.; Renzl, B.; Matzler, K. (2006) Who Trusts? Personality, Trust and Knowledge Sharing. *Management Learning*, **37**(4): 523-540.

Morgan, G. (1986) Images of Organization. London: Sage.

Morgan, M.G. and M. Henrion (1999) Uncertainty: A guide to dealing with uncertainty in quantitative risk and policy analysis. Cambridge University Press, New York, NY.

Morse J.M., Barrett M., Mayan M., Olson K. & Spiers J. (2002) Verification strategies for establishing reliability and validity in qualitative research. *International Journal of Qualitative Methods*, 1(2), Article 2.

Munton, R. (2003) 'Deliberative Democracy and Environmental Decision-Making' in F. Berkhout, M. Leach and I. Scoones (eds) Negotiating Environmental Change. Cheltenham: Edward Elgar.

NAO National Audit Office (2000) *Supporting Innovation: managing risk in government departments.* London, UK.

Nassiri-Mofakham, F.; Ghasem-Aghaee, M.A.N.; Dastjerdi, A.D. (2009) A heuristic personality-based bilateral multi-issue bargaining model in electronic commerce**.** *International Journal of Human-Computer Studies***, 67**(1): 1-35

Nassiri-Mofakam, F.; Ghasem-Aghaee, N.; Nematbakhash, M.A.; Baraani-Dasterdi, A. (2008) A personality-based simulation of bargaining in e-commerce. *Simulation & Gaming*, **39**(1) 83-100

Nesselroade, J.R. (1988) Some implications of the trait-state distinction for the study of development over the life span: The case of personality. *In P.B. Baltes, D.L. Featherman & R.M. Lerner (Eds.), Life-span development and behaviour (Vol.8, pp. 163-189).* Hillsdale, NJ: Elrbaum.

Neuberg, L.; Bertels, K. (2003) Heterogeneous Trading Agents. *Wiley Periodicals, Inc*., 8(5): 28-35.

Nonaka, I.; Takeuchi, H. (1995) *The knowledge-creating company. How Japanese companies create the dynamics of innovation.* New York: Oxford University Press.

North, M. J. & Macal, C. M. (2007) *Managing business complexity: Discovering strategic solutions with agent-based modelling and simulation.* New York: Oxford University Press.

Notsu, A.; Ichihashi, H.; Honda, K. (2006) Agent-Based Simulation about Social Value Emergence Based on Perceptual Balance. *2006 IEEE International Conference on Systems, Man, and Cybernetics, October 8-11, 2006, Taipei, Taiwan*.

Nute, D., Potter, W.D., Maier, F., Wang, J., Twery, M., Rauscher, H.M.,Knopp, P., Thomasma, S., Dass, M., Uchiyama, H., Glende, A. (2004) NED-2: an agent-based decision support system for forest ecosystem management. *Environ. Model. Softw*. **19**: 831-843.

NRC National Research Council (1996). Understanding Risk: Informing Decisions in a Democratic Society. National Academy Press, Washington, DC: USA

OXERA Oxford Economic Research Associates (2000) *Policy, risk and science: Securing and using scientific advice, Contract Research Report 295/2000*, HSE Books, Sudbury.

Page, M. M., ed. (1983). Personality. Current Theory and Research*. Lincoln: University of Nebraska Press.*

Paton, R. (1984) Power in Organisations, *Organisations,* 105-110*.*

Patton, M.Q. (1987) How to use Qualitative Methods in Evaluation. Newsbury Park: Sage Publications.

Patton, M. Q. (1990). *Qualitative evaluation and research methods.* (2nd Ed.) Newbury Park: Sage Publications.

Paul, R.J., Giaglis, G.M., Hlupic, V. (1999), "Integrating simulation in organisational design studies", *International Journal of Information Management*, Vol. 19 No.3, pp.219-36.

Perez, L.; Dragicevic, S. (2009) An agent-based approach for modeling dynamics of contagious disease spread. *International Journal of Health Geographics*, **8**:50

Pervin, L.A. (1987), Person-environment congruence in the light of the person-situation controversy. Journal of Vocational behaviour, Volume 31, Issue 3, pp 222-230.

Pfeffer, J.; Sutton, R. (1999) Knowledge "What" to do is not enough: Turning knowledge into action. *California Management Review, 42* (1), 83-108.

Pollard, S.J.T.; Davies, G.J.; Coley, F.; Lemon, M. (2008) Better environmental decision making – Recent progress and future trends. *Science of the Total Environment,* **400**(1-3): 20-31.

POST Parliamentary Office of Science and Technology (2004) *Handling uncertainty in scientific advice. Postnote no. 220*, London, UK

Powell, M.R. (1999) Science at EPA: information in the regulatory process, Washington: Resources for the Future.

Power, M.; McCarty, L.S. (2006) Environmental Risk Management Decision-Making in a Societal Context. RedOrbit

Prada, R.; Paiva, A. (2009) Teaming up humans with autonomous synthetic characters. *Artificial Intelligence,* **173**(1): 80-103

Presidential Commission (The Presidential/Congressional Commission on Risk Assessment and Risk Management). 1997. Framework for Environmental Health Risk

Management. Final report volume 1. Government Printing Office, Washington, DC, USA

Rahim, M.A.; Antonioni, D.; Psenicka, C. (2001) A structural equation model of leader power, subordinates' styles of handling conflict, and job performance. *The International Journal of Conflict Management*, 12(3): 191-211

RCEP Report of the Royal Commission on Environmental Pollution (1998) Setting environmental standards. 21st, The Stationery Office, London.

Rempel, J.K.; Holmes, J.G.; Zanna, M.P. (1985) Trust in Close Relationships, Journal of *Personality and Social Psychology*, **49**: 95-112.

Reynolds, B.; Karraker, K. (2003) A Big Five model of disposition and situation interaction: Why a "helpful" person may not always behave helpfully. *New Ideas in Psychology*, **21**(1): 1-13.

Richetin J.; Sengupta A.; Perugini M.; Adjali I.; Hurling R. (2010) A Micro-level simulation for the prediction of intention and behaviour, *Cognitive Systems Research* **11**(2): pp 181-193

Rizzo, P.; Veloso, M.; Miceli, M.; Cesta, A. (1997), Personality-driven social behaviours in believable agents. American Institute of Aeronautics and Astronautics Symposium on Social Intelligence Agents, Technical Report FS-97-02.

Robbins, S.P. (2003) Organisational behaviour, 10th ed., New Jersey: Prentice Hall, Inc.

Rothstein, H.; Irving, P.; Walden, T.; Yearsley, R. (2006) The risks of risk-based regulation: Insights from the environmental policy domain, *Environment International*, **32**: 1056-1065.

Rothstein, H. (2003) Precautionary Bans or Sacrificial Lambs? Participative regulation and the reform of the UK food safety regime. CARR Discussion Paper No.15. London: London School of Economics.

Rotter, J.B. (1971) Generalized Expectancies of Interpersonal Trust. *American Psychologist,* **26**: 443-452.

Sacks, F.M.; Svetkey, L.P.; Vollmer, M.D.; Appel, L.J.; Bray, G.A.; Harsha, D.; Obarzanek, E.; Conlin, P.R.; Miller, E.R.; Simons-Morton, D.G.; Karanja, N.; Lin, P.-H. (2001) Effects on blood pressure of reduced dietary sodium and the dietary approaches to stop Hypertension (DASH) Diet. *The New England Journal of Medicine*, **344**(1): 3-10.

Santos, R.; Marreiros, G.; Ramos, C.; Neves, J.; Bulas-Cruz, J (2010) Using Personality types to support argumentation, *Lecture Notes in Computer Science* **6057**: 292-304

Saucier, G.; Bel-Bahar, T.; Fernandez, C. (2007) What modifies the expression of personality tendencies? Defining basic domains of situation variables. *Journal of Personality*, **75**(3): 479-504.

Scholten, L.; Van Knippenberg, D.; Nijstad, B.A.; De Dreu, C.K.W. (2007) Motivated information processing and group decision-making: Effects of process accountability on information processing and decision quality. *Journal of Experimental Social Psychology*, **43**: 539-552.

Schramm, W. (1971), "Notes on case studies of instructional media projects", working paper, Academy for Educational Development, Washington, DC.

Schutte, N.S.; Malouff, J.M.; Segrera, E.; Wolf, A.; Rodgers, L. (2003) States reflecting the Big Five dimensions. *Personality and Individual Differences*, **34**(4): 591–603

Science Advisory Council. (2006) End to end review of science into policy in Defra. Department of Environment, Food and Rural Affairs, Paper SAC (06) 22.

Seo, T.; Tsuchi, H.; Metcalfe, R.; Suyama, Y.; Takase, H.; Bowden, A.; Toida, M.; Furuichi, M.; Matsumura, A.; Yoshimura, M.; Horio, A. (2004) A decision-making methodology taking into account uncertainties and its possible application for the selection of preliminary investigation areas. (Proceedings of DisTec 2004, 26th - 28th April, Berlin, 82-88.)

Shafer, G. (1976) A Mathematical Theory of Evidence, *Princeton University Press*.

Shoda, Y. (1999) A unified framework for the study of behavioural consistency: bridging person x situation interaction and the consistency paradox. *European Journal of Personality*, **13**: 361-387.

Shoda, Y.; LeeTiernan, S.; Mischel, W. (2002) Personality as a dynamical system: emergence of stability and distinctiveness from intra- and interpersonal interactions. *Personality and Social Psychology Review*, **6**(4): 316-325

Slater, R. Frederickson, J. Thomas, C. Weild, D. Potter, S. (2006) A critical evaluation of partnerships in municipal waste management in England. *Resource, Conservation and Recycling*, **51**: 643-664

Slovic, P. (2000) The Perception of Risk. Earthscan Publications, Sterling, VA

Slovic, P., Fischhoff, B., Lichtenstein, S. (1977) Behavioural Decision Theory. *Annual Review of Psychology*, 28: 1-39

Slovic, P., Fischhoff, B., Lichtenstein, S. (1982) Facts versus fears: Understanding perceived risk. *Judgment under Uncertainty: Heuristics and Biases*, pp. 463-

489. Kahneman, D., Slovic, P. and Tversky, A., Editors, Cambridge University Press, Cambridge, United Kingdom.

Smajgl A.; Morris S.; Heckbert S.; (2009) Water Policy Impact Assessment – Combining Modelling Techniques in the Great Barrier Reef Region, *Water policy* 11(2): pp 191-202.

Sorrentino, R.M.;Smithson, M.; Hodson, G.; Roney, C.J.R.; Walker, A.M. (2003) The theory of uncertainty orientation: a mathematical reformulation. *Journal of Mathematical Psychology,* **47**: 132-149.

Sorrentino, R.M.; Roney, C.J.R.; Hanna, S.E. (1992) Uncertainty orientation. In: Smith, C.P., Atkinson, J.W. and McClelland, D.C., Editors. *Motivation and personality: The handbook of thematic analysis*, New York: Cambridge University Press, pp. 419–427.

Smithson, M. (1989) *Ignorance and Uncertainty: Emerging Paradigms*, Springer Verlag, New York

Spender, J.-C. (1996) *Competitive advantage from tacit knowledge?* In *Organization learning an competitive advantage.* B. Moingeon and A. Edmonson (eds.), 56-73. London: Sage.

Stephenson, T. (1985) *Management: a political activity*. London: Macmillan.

Stirling, A. (1999) 'Risk at a Turning Point?' *Journal of Environmental Medicine* 1:119-126.

Stirling, A. (2003) Risk, uncertainty and precaution: Some instrumental implications from the social sciences. In *Negotiating change*, edited by F. Berkhout, M. Leach, and I. Scoones. Aldershot, England: Edward Elgar.

Strategy Unit (2002), *Risk: improving Government's capability to handle risk and uncertainty,* The Strategy Unit, London. Available at: http://www.number-10.gov.uk/SU/RISK/risk/home.html.

Swan, J.; Scarbrough, H.; Robertson, M. (2002) The Construction of "Communities of Practice" in the Management of Innovation, *Management Learning*, **33**(4): 477-96.

Tabara, J.D.; Roca, E.; Madrid, C.; Valkering, P.; Wallman, P.; Weaver, P. (2008) Integrated sustainability assessment of water systems: lessons from the Ebro River Basin. *International Journal of Innovation and Sustainability Development,* **3**(1-2): 48-69.

Ten Berge, M.A.; De Raad, B. (1999) Taxonomies of situations from a trait psychological perspective. A review. *European Journal of Personality*, **13**: 337-360.

Ten Berge, M.A.; De Raad, B. (2002) The structure of situations from a personality perspective. *European Journal of Personality*, **16**: 81-102.

Thomsen, L.L.; Thomsen, B. (1997) Mobile Agents – The New Paradigm in Computing. ICL Systems Journal **12**(1): 14-27.

Tuler, S.; Webler, T.; Finson, R. (2005) Competing perspectives on public involvement: Planning for risk characterisation and risk communication about radiological contamination for national laboratory. *Health, Risk & Society,* 7(3): 247-266

Tversky, A.; Kahneman, D. (1992) Advances in Prospect Theory: Cumulative Representation of Uncertainty, *Journal of Risk and Uncertainty*, **5**: 297-323.

Uzzi, B. (1997) Social structure and competition in interfirm networks: The paradox of embeddedness. *Administrative Science Quarterly*, **42**: 35-67.

Wainwright, D. (1997) Can Sociological Research Be Qualitative, Critical, and Valid? The Qualitative Report, **3**(2): Available: http://www.nova.edu/ssss/QR/QR3-2/wain.html

Wang, C.L.; Ahmed, P.K.; Rafiq, M. (2008) Knowledge management orientation: Construct development and empirical validation. *European Journal of Information Systems*, **17**(3): 219-235.

Wang, C.L.; Hult, G.T.M.; Ketchen, D.J.; Ahmed, P.K. (2009) Knowledge management orientation, market orientation, and firm performance: An integration and empirical examination. *Journal of Strategic Marketing*, **17**(2): 99-122.

Wang, J.; Wysk, R.A. (2008) A Pi-Calculus Formalism for Discrete Event Simulation. *Proceedings of the 2008 Winter Simulation Conference, S.J. Mason, R.R. Hill, L. Monch, O. Rose, T. Jefferson, J.W. Fowler eds*.

Wasko, M.M.; Faraj, S. (2005) Why should I share? Examining social capital and knowledge contribution in electronic networks of practice, *MIS Quarterly* 29(1): 35–58.

Whittom A.; Roy M.-C. (2009) Considering Participant Motivation In Knowledge Management Projects, Journal of Knowledge Management Practice, 10(2).

Wiener, J.B. (2004) The regulation of technology, and the technology of regulation, *Technology in Society*, **26**: 483-500.

Wisker, G. (2001) *The Postgraduate Research Handbook*. London: Palgrave.

Withey, M.J.; Gellatly, I.R.; Annett, M. (2005) The moderating effect of situation strength on the relationship between personality and provision of effort. *Journal of Applied Social Psychology*, **35**(8): 1587-1608.

Wojcik, L.A (2004) Airline personalities and air traffic flow management: A simple agent-based model by MITRE Corporation. American Institute of Aeronautics and Astronautics 4th Aviation Technology, Integration and Operation (ATIO) Forum, Chicago, Illinois

Xu, J., & Griffiths, T.L. (2010). A rational analysis of the effects of memory biases on serial reproduction.*Cognitive Psychology*, **60**: 107-126.

Yamamoto, J.; Sycara, K. (2001) A Stable and Efficient Buyer Coalition formation Scheme for E-Marketplace, AGENT'01, May 28-June 1, 2001, Montreal, Quebec, Canada.

Yearsley, R.; Pollard, S.J.T. (2001) VALDOR Symposium Addressing Transparency in Risk Assessment and Decision Making. *Journal of Radiologic al Protection*, **21**: 324-325.

Yin. R.K. (1984) *Case Study Research – Design and Methods,* Beve rly Hills, CA: Sage Publications.

Zhang, T.; Zhang, D. (2007) Agent-based simulation of consumer purchase decision making and the decoy effect. *Journal of Business Research*, **60**(8): 912-922

This page is intentionally blank

LIST OF APPENDICES

The following files are enclosed on the CD attached to this thesis.

Appendix A: Exploratory interview transcript

Appendix B: Participants by sector

Appendix C: Semi-structured interview schedule

Appendix D: Semi-structured interview transcript:

Case study 1 – Nuclear Waste

Appendix E: Semi-structured interview transcript:

Case study 2 – Salt Intake

Appendix F: Semi-structured interview transcript:

Case study 3 – Avian Influenza

Appendix G: Source code to the two-agent model

Appendix H: Published work

This page is intentionally blank